PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

Edited by M. R. Banks and M. J. Brown

and Published by the Society

Hobart

Tasmania

31 OCTOBER 1999

VOLUME 133 • PART 1

PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

Edited by M. R. Banks and M. J. Brown

and Published by the Society

Hobart

Tasmania

MUSEUM OF VICTORIA
29 MAY 2000

31 OCTOBER 1999

ISSN 0080-4703

VOLUME 133 • PART 1

Museum Victoria
71409

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 133(1)

Contents

page

Annual report iii

Refereed papers:

JACKSON, W.D. — The Tasmanian legacy of man and fire 1

BROTHERS, N. & HARRIS, S. — The effects of fire on burrow-nesting seabirds particularly short-tailed shearwaters *(Puffinus tenuirostris)* and their habitat in Tasmania 15

MEGGS, J.M. & TAYLOR, R.J. — Distribution and conservation status of the Mt Mangana stag beetle, *Lissotes menalcas* (Coleoptera: Lucanidae) 23

BANKS, M.R., & LEAMAN, D.E. — Charles Darwin's field notes on the geology of Hobart Town — a modern appraisal 29

LING, J.K. — Elephant seal oil cargoes from King Island, Bass Strait, 1802–1819: with estimates of numbers killed and size of the original population 51

MELVILLE, J. & SWAIN, R. — Habitat associations and natural history of the Tasmanian "snow skinks" (*Niveoscincus* spp.) 57

LEAMAN, D.E. — The nature of jointing, Tasman Peninsula, southern Tasmania 65

SMART, D., RUBIDGE, S., MCCARTNEY, P. & VAN DEN BROEK, C. — Tasmania's aquaculture industry: a ten-year review of improved diving safety 77

HARRIS, S. & MCKENNY, H. — Preservation Island, Furneaux Group: Two hundred years of vegetation change 85

KIRKPATRICK, J.B. — The characteristics and management problems of the vegetation and flora of the Huntingfield Area, southern Tasmania 103

BUCHANAN, A.M. — A New Species of *Euchiton* (Gnaphalieae: Asteraceae) from Southern Tasmania, Australia 115

Guide to authors 117

Publication of this volume was generously supported by the Government of Tasmania and the University of Tasmania.

ROYAL SOCIETY OF TASMANIA
Annual Report for the Year 1998

The Council has the honour to present to members the following report on the activities of the Society during the year.

Council and Office Bearers

Patron
Her Majesty the Queen

President
His Excellency, the Honourable Sir Guy Green AC, KBE
The Governor of Tasmania

Vice-Presidents
Dr Shirley Jeffrey AM, FAA
Ms Patricia Sabine

Council
Dr Alison Alexander
Mr Alan Blow OAM, QC
Dr Peter Smith
Dr Brian Yates
Professor Campbell Macknight*
Mr Chris Tassell*
[*Northern Branch Nominees]

Past Vice-President
Dr John Thorne

Honorary Secretary
Dr Andrew Rozefelds

Honorary Treasurer
Dr David Leaman

Honorary Auditor
Mr L. Cox

Honorary Editor
Dr Max Banks AM

Honorary Assistant Editor
Dr Mick Brown

President

His Excellency, Sir Guy Green, Governor of Tasmania took the Chair as President of the Society at the Annual General Meeting of the Society on 10 March 1998. He presented the inaugural M.R. Banks Medal to Dr T. MacDougall, Chief Research Scientist (CSIRO Marine Research) for his outstanding contributions to knowledge of ocean mixing processes. His Excellency also attended the Annual General Meeting of the Northern Branch of the Society, on the 6 March 1998.

Bereavements

Mr Frank Cumbrae-Stewart, a member of the Society since 1948, died in August 1998.

Membership of the Society

The membership is 385, a decrease of 24 relative to 1997 and is made up as follows:

President	1	
Honorary Members	6	(2)
Life Members	30	(9)
Ordinary Members		
receiving *Papers & Proceedings*	219	(32)
not receiving *Papers & Proceedings*	110	(31)
Associate	19	(6)
Total	385	(80)

Figures in brackets represent Northern Branch members.

Staff

The Society would like to thank Ms Vicki Farmery and Ms Joanna Huxley of the TMAG, and volunteer Ms Judith Parkhurst for their help throughout the year.

Council Meetings

Eight meetings of Council were held during the year to cover many ongoing issues. These included the Royal Society Bursaries, new Royal Society Medals and Awards, the "Originally Tasmanian" project, the lecture programme including "The Year of The Ocean" Public Symposium series, Royal Society finances, editorial matters, the Royal Society Foundation, a new simple information brochure, recruiting volunteers to help with the Society's workload, the viability of a new branch in northwestern Tasmania, increasing membership among younger people and other matters.

The Royal Society of Tasmania Foundation

Funds in the Foundation grew slowly during the year. Details are provided in the Report of the Honorary Treasurer. Consideration was given to ways of increasing the flow of funds into the Foundation but no action was taken pending clarification of tax deductibility of donations. An initial approach to the Australian Taxation Office for deductibility was unsuccessful but is being pursued further. The Rules of the Foundation were amended to allow greater flexibility in the choice of Chairman and Secretary.

Society Honours and Honours Committee

The Honours Committee, Dr S.W. Jeffrey (Chair: Marine Science), Professor J.B. Reid (Plant Science), Professor O.M. Roe (History) and Dr P.W. Smith (Chemistry), fine tuned the new Doctoral Award during 1998, which was accepted by the Royal Society Council and membership. The Award carries a prize of not less than $500. In October 1998, calls for applicants and conditions of the Award were widely circulated throughout Tasmanian academic institutions and the Press, with a closing date for the first award of 30 November 1998. It was planned the first award would be made at the Society's Annual General Meeting on 2 March 1999.

Seven applications of a very high standard were received from candidates in the fields of medicine, government, astrophysics, microbial ecology, chemistry, bacteriology and zoology, and these were examined independently by the Honours Committee members, according to the criteria governing the Award. The PhD project of Dr Simon Ellingsen in the field of Astrophysics was deemed of the highest order, and the Committee's recommendation that the Inaugural (1998) award be made to Dr Ellingsen was accepted by Council.

Grants to the Society

Council received support from the State Government in the form of a special grant of $2000 towards the cost of the Society's publication programme and, through Arts Tasmania, a grant of $2100 towards the administration and promotion of the Society. The publication programme was also supported by a grant of $3000 from the University of Tasmania. The Society acknowledges receipt of these grants with thanks, and appreciates the support implied by them.

Treasurer's Report

At the end of 1998 the financial resources of the Society were under some strain. There are several reasons for this. There has been a continuing high level of activity in terms of provisions of meetings, publications and student support. We should not seek to minimise these contributions but costs associated with these projects, notably meeting notices and postage, have increased and the income base has decreased.

The decline in number of members, coupled with negligible earnings on investments, does expose the Society to a "need to cut the cloth"; actions which would become urgent if any of the supporting government funds were to be reduced or denied.

Examination of the objectives of the Society shows that there is little scope for significant adjustment on this side of the ledger without damage to services or objectives. For example, postage costs could be reduced by changing the frequency of meeting notices and consolidating, wherever possible, such notices with other material. There are limits to such changes, and most amount to major changes in services for relatively little gain — when seen in total context. Such postal changes might provide a cost reduction of 15% but, useful as this might be, it is minuscule in terms of the entire budget or the possible increases in receipts were membership numbers or interest rates to change.

This review shows that stabilisation of the financial resources of the Society, now in decline, can only be effected by changes in the income side of the ledger. Increases in subscription levels lead to loss of members and cannot raise sufficient income unless subscription increases are large — an unacceptable solution.

There are however, two things every member can do to assist and ensure the long term viability of the Society:
(1) encourage new members, and
(2) make a donation to the Foundation Fund each year.

One hundred new members would greatly ease the current burden and allow maintenance of all activities.

We should also realise that, eventually and in the absence of government support (threatened), income from the Foundation Fund will be crucial. That fund needs to grow and be large enough to provide sufficient earnings even in difficult financial times. A useful goal for this fund is about $200,000. Every contribution, however small, will help achieve this. Please try to help.

Library Report

1998 has seen the completion of a full year during which the Royal Society collection has been located on Level 5 of the Morris Miller building, in what is still anticipated to be temporary accommodation, pending an eventual move to Level 1 in the same building. Further developments in University and Library accommodation requirements have now determined that the Royal Society collection will

M.R. Banks Medal

remain on Level 5 for some time yet, although access and use arrangements have not significantly altered since the initial move.

The sizeable increase in the amount of binding, first undertaken for the Library in 1997, was maintained this year, with a total of 174 volumes being completed. This rate of binding ensures that most journal volumes are bound on completion and that any backlog of binding remains small.

The position of Library Assistant (Special Collections) was unfortunately not renewed at the end of the year, due to the overall staff reduction necessary as part of the University Library restructure during 1998. Day-to-day maintenance of the Library now falls to the University Library Collection Management Unit whilst the Client Services sections assist in the provision of service to Library users.

Much of the clerical work associated with the Library has now been transferred to the Serials Section of the University Library, and accessioning, mailing and general maintenance is now undertaken by the staff there. Advantages of this change are, significantly, the more rapid inclusion of all current serials titles to the Library database, a process which will result in further progress with the recataloguing of titles. Receipt of Library mail has also been streamlined, with the Library having a unique mailbox number within the University internal mail system, which ensures direct delivery to the Library rather than through the Royal Society mail box at the GPO via the Museum.

During the year, five new titles were added to the exchange agreement listing as a result of successful communication with producers of botanical titles from South America.

Progress continues on the production of a comprehensive listing and guide to the Royal Society Library holdings, but proof-reading and related activity has held up its production until some time in 1999. The listing, when complete, will be produced in limited numbers for other libraries and users, and it is hoped to incorporate access to the electronic version of the document through the web pages.

Shane Roberts held the position of Library Assistant for most of the year, with occasional assistance, as required, from Emilia Ward and Judy Jeffery. Graeme Rayner continues to hold the position of Royal Society Librarian as part of the Collection Management/Special Collections portfolio of the University Library.

During the year 242 library users signed the Library visitors book whilst 38 Archives users were recorded. Loan statistics for the year would appear to be lower at 29, but the lending of Library material is an insignificant part of its total use, given the ready availability of photocopying facilities.

Dr Trevor McDougall, left, with his M.R. Banks Medal, and Dr Max Banks, after whom the new award is named. Photograph courtesy of The Mercury.

Publications

Volume 132 of the *Papers and Proceedings* was published late in December. It comprised the Annual Report for 1997 and eleven papers. The papers dealt with Tasmanian mosses, a daisy, plant ecology, parasites in Tasmanian birds, the giant crab, a new fly, carp in a Tasmanian lake, Tasmanian fire regimes since the early 1800s and landscape instability. These papers were submitted by authors from Tasmania, other Australian States and the USA — the authors having affiliations with State Departments in Tasmania, museums in Tasmania and NSW, and universities in Tasmania, South Australia and the United States. The Society acknowledges with thanks the help of Mrs A. Jones, as sub-editor, and Ms J. Pongratz, as typesetter and formatter, in the production of the volume.

Bursaries

The Royal Society with Associated Scientific Societies arranged for the presentation of Bursaries to three Year 12 students during the year. The Bursaries were awarded to Mr Ashley Norris of Claremont College, to attend the International Youth Science Forum in London; Mr Hans Schmidt, Launceston College, to attend the National Youth Science Forum in Pretoria; and Ms Jessica Trebilco, The Friends' School, to compete at the Biology Olympiad in Kiel, Germany. She won a Gold Medal at that event.

Mr Andrew Howell, winner of a Bursary in 1997, attended the International Youth Science Forum in London in that year. He was selected to return to London as a staff member of the 1998 Forum and has been awarded a scholarship by the Australian Institute of Mining and Metallurgy to pursue studies towards a degree in Mining Engineering at the University of Tasmania and the University of NSW.

During 1998, the Tasmania Divisions of ANZAAS, the Institution of Surveyors, the Geological Society of Australia, the Australian Society for Microbiology, the Australian Marine Sciences Association, the Australian Institute of Physics, the Institute of Foresters and the Faculty of Science and Engineering, University of Tasmania, made donations towards the bursaries.

The first steps were taken to put into place a programme

to interest Tasmanian secondary students in becoming involved in the Science Olympiads and Science Forums, and to assist the organisation of training programmes. Initially, with the aid of Computerland, a website has been set up which will provide internet access to study material for students.

Programme in 1998

In addition to regular meetings and lectures in the Royal Society Room, 1998 saw a new programme initiative developed, with the Royal Society joining with several other Hobart academic groups (the University of Tasmania and the Australian Marine Sciences Association) to present six wide-ranging public symposia to celebrate UNESCO's 1998 Year of the Ocean. These symposia, featuring 4–6 lecturers per session and chaired by scientific experts, were held at the Stanley Burbury Theatre, University of Tasmania, and attracted enthusiastic audiences ranging from 250–400 persons. These were held every 4–6 weeks on Tuesday evenings from 7.30–9.30 pm from June to November 1998. Information on the symposia was widely circulated and advertised, and targeted the general public, schools, science teachers, university students, the scientific community and Royal Society members. Over 35 speakers and six chairpersons drawn from the Tasmanian scientific community participated, and vigorous discussions followed each Symposium presentation.

In addition, seven regular Royal Society meetings were held with lectures on a variety of topics from local history, forest regeneration, poppies and the pharmaceutical industry, medals and coinage as mirrors of history, Tasmanian economics and the Wreck of the *Sydney Cove*.

A special event in November was a visit by Royal Society members to see the treasures of the Royal Society Library at the University of Tasmania, guided by Mr Graeme Rayner. Members were most impressed by the holdings, particularly the rare book collections.

Lecture topics and "Year of the Ocean" Public Symposia for 1998 are listed below.

March 10 — Annual General Meeting: "The oceans's role in climate change" Dr T. McDougall.
April 7 — "Sandy Bay — A social history" Ms N. Goc.
May 5 — "The forest as Phoenix" Dr R.C. Ellis.
June 2 — "Poppies in Tasmania: the flowering of the pharmaceutical industry" Dr C. Garland.
June 23 — Symposium 1, "Tasmania's unique marine life" Mr J. Bryan, Ms K. Gowlett-Holmes and Mr B. Bruce.
July 7 — Symposium 2, "The blue planet" Drs N. Bray, G. Cresswell, B. Tilbrook, G. Meyers and S. Rintoul.
August 4 – Symposium 3, "Biological impacts of ozone depletion: The UV hazard" Drs H. Marchant, M Nunez, S. Jeffrey, A. McMinn, S. Nicol and Prof. T. Dwyer.
September 1: Mr R. MacNeice "Medals: Mirrors of history"
September 8: Symposium 4, "Marine reserves — what for?" Prof. C. Johnson, Dr N. Barratt, Mr D. Nicol, Ms J. Scott, Mr B. Lister and Dr C. Buxton.
October 6 — "Economics of relevance to Tasmania" Prof. B. Felmingham.
October 13 — Symposium 5, "Marine farming: where to now?" Mr P. Shelley, Prof N. Pankhurst, Drs M. Brown, D. Moreland, B. Ward, P. Thompson, Mr C. Sumner and Mr D. Ross.
November 3 — Symposium 6, "Sea harvests: Chemicals, minerals, fish – what is the future?" Drs K. Sainsbury, A. Jordan, S. Nicol, H. Wildman, P. Nicols, and Mr J. Davidson.
December 1 — Christmas Function: "Cargo for the colony — The wreck of the *Sydney Cove*" Ms L. Clark, and Bursary Winners experiences, Ms J. Trebilco and Mr A. Norris.

Northern Branch

Branch Council

Chairman	Professor Campbell Macknight
Vice-Chairman	Ms Judith Hollingworth
Past Chairman	Mr Elvin Fist
Honorary Secretary	Mr Chris Tassell
Honorary Treasurer	Mrs Doreen Girvan
Committee	Mrs Christine Beswick
	Mrs Mary Cameron
	Mr Brian East
	Mr David Hannan

The Northern Branch Council met five times during the year. Lecture topics for the Northern Branch Programme are listed below.

February 6 — "Leaving hospital and returning home: Discharge destinations for people with schizophrenia" Dr R. Bland.
March 6 — Annual General Meeting. "Fishing with a hammer in Australia and Antarctica" Dr A. Ritchie.
April 3 — "Advances in the treatment of leukemia" Dr K. Rooney.
May 1 — Excursion to NDA Computing: "From Gutenberg to Gates: The internet as a communications medium" Mr N. Davies.
June 5 — "Tasmanian Alkaloids — Industry from science". Mr B. Hartnett.
June 19 — Royal Society of Tasmania Bursary was presented to Hans Schmidt by Dr Frank Madill.
July 3 — Members Night: "Fox's feast" Mr P. Webb; "Regions in transition" Dr Jerry Courvisanos; "The formative years of Kelsall & Kemp" Mr M. Hart.
August 7 — "Queen Victoria Museum at the Inveresk railway yards" Mr C. Tassell.
September 4 — "The semaphore/telegraph in northern Tasmania" Mr W. Shipp and Ms D. Phillips. Mr H. Schmidt (Tasmanian Bursary awardee) spoke about his trip, including the Youth Science Congress.
October 2 — Students Night: "Pollution levels in worlds cleanest air" Ms R. Webb; "Portable water analysis" Ms F. Beach; "Shell deposition in abalone" Ms K. McBean.
November 6 — "Symposium on the problem of siltation in the Tamar River" Mr H. Joyce, Mr D. Girling and Mr G. Brayford.
December 5 — Members Night: "Hunter revisited" Mrs B. Payne; "Molilem's pine" Mr B. Stevens; "Col Patterson and the North Esk" Prof. C. Macknight.

Nominees to Other Bodies

The Royal Society nominates members to the Boards of Trustees of the Tasmanian Museum and Art Gallery (TMAG) and the Royal Tasmanian Botanical Gardens (RTBG). Professor Jim Reid and Dr Tony Brown were the Royal Society nominees to the TMAG Board, while Dr Mick Brown was the nominee to the RTBG Board. A report for 1998 from each of these institutions follows.

Tasmanian Museum and Art Gallery

1998 was a year of innovative locally produced public programmes such as:

- *Sun Sea and Sextant: navigation the hard way* (TMAG and MMT)
- *Special Clothes* (TMAG)
- *Tasmanian Tiger: the mystery of the Thylacine* (TMAG) and
- *Cargo for the Colony: the wreck of the Sydney Cove* (QVMAG)

1998 also saw the consolidation of the general collection-based and research activity.

As a result of a change in government at the September State elections the TMAG has been transferred from the Department of Education, Training and Community and Cultural Development to the newly structured Department of State Development.

The Minister for State Development is the Premier, the Hon. Jim Bacon, and the inclusion of TMAG in the Department of State Development demonstrates this government's recognition of the key role the TMAG and its collections can play in promoting in the image, identity, and information resource base of Tasmania.

Trustee Membership

Dr Tony Brown, was re-elected as Chairman of Trustees at the first Trustees meeting of 1998. The Lord Mayor, Alderman Dr John Freeman, replaced Alderman Ian Malcolm as the Hobart City Council representative after Alderman Malcolm's resignation as a Trustee on 7 August 1998.

Staff Activity

As a result of an across-the-board Public Service review, all museum positions have been reclassified and adjusted according the standard "four streams" benchmark.

Museum staff and projects have won significant awards and grants in 1998. A selection is listed below.

Trainee Collections Manager (Indigenous Cultures), Tony Brown, has been awarded an Aboriginal Study Scholarship to enable him to complete a BA degree at the University of Tasmania as a full-time student from 1999.

Curator – Invertebrate Zoology, Roger Buttermore, travelled overseas on his Churchill Fellowship, awarded for his work on bumblebees (*Bombus bombus*). He has made significant contacts and gathered vital information to enhance his project.

Dr Gintaras Kantvilas, Coordinating Curator (Sciences), continued his work on Tasmanian lichens at the British Museum of Natural History.

Mr David Hansen, Coordinating Curator (Humanities), was awarded a Paul Mellon Fellowship ($50 000) for major research on the art and life of John Glover in the United Kingdom in 1999. This is in addition to a Visions Australia Development grant for the John Glover exhibition ($38 000)

The *Tasmanian Tiger* Exhibition has been awarded two Commonwealth Government Visions Australia grants of $138 000 for exhibition development and touring.

Dr David Pemberton, Senior Curator Zoology, and Mr Noel Kemp, Curator Geology, attended and gave papers at international conferences in South Africa. Alison Melrose, Curator Information Services, and Carolyn Parsons, Visitor Services, attended the Triennial Conference of the International Council of Museums in Melbourne.

Honorary Curators have been appointed in a wide range of disciplines including Dr George Bornemizza in Entomology and Mr Alan Rider in Horology.

The Heritage Furniture Unit, staffed by Mr Tony Coleman was established and has been working effectively.

Director Patricia Sabine continued her membership of the Heritage Collections Council as a representative of the Council of Australian Art Museum Directors and the State Government of Tasmania.

Facilities Management

The Museum Courtyard Cafe opened on 1 June and has been well patronised.

The stonework restoration on the Custom House is almost completed.

Collections

There have been significant gifts and bequests to the TMAG in 1998 including

- a collection of historic maps of Tasmania from the estate of the late Dr Lamprell;
- a collection of 19th-century miniatures and other works from the Dawes family;
- an extensive collection of works of art and other material from the estate of the late Benjamin Sheppard;
- dress uniform of a former Governor of Tasmania, Sir Ronald Cross;
- items of costume from the estate of the late Sir John Cameron;
- sixteen drawers of world forest beetle specimens collected and curated by Dr George Bornemizza;
- two Wainwright and Dowling portraits from a private collection in Hobart;
- a suite of bas relief sculptures by Stephen Walker donated by the Risby family and installed in the PSR/ Museum Cottage courtyard.

Public Programmes

Twelve major exhibitions were opened in 1998, three were developed in-house; in discipline terms, three were art based, five social history based and four environment/ science based. Although attendance did not reach the record peak of 1997, it remained consistent throughout the year, with strong attendance from schools.

Argonauts: Graceful Sailors of the Sea, an exhibition on the paper nautilus, was shown at the Australian Museum as part of the Sydney Olympic Cultural Festival, *A Sea Change.*

Royal Tasmanian Botanical Gardens

Achievements during the year included construction of the new *Botanical Discovery Centre* funded by the Tasmanian Government; construction of the Australian Antarctic Foundation Subantarctic Plant House; significant progress

in the fight against *Armillaria*; and success in obtaining a National Estate Grant from the Commonwealth Government for the restoration of the Gardens' 1845 sandstone gatehouse.

The *Botanical Discovery Centre* development will give the Gardens world-class visitor facilities. Construction of the building component of the $1.58 million Centre was completed in November. The twin-peaked building fits beautifully into the Gardens environment, and has been greeted with general acclaim. Interpretation design and construction began in September and is expected to be complete in January 1999. The innovative display will focus on the role of plants in supporting all life on earth and will use WWW technology to ensure flexibility and easy updating of displays. The development includes a retail facility as well as renovations and an external deck for the existing adjacent restaurant.

Construction of the *Australian Antarctic Foundation Subantarctic Plant House* was also completed during the year, thanks to additional funding from the Australian Antarctic Foundation. The design is an innovative and unique teardrop shaped, solid-sided building with a clear roof. Other sources of funds this year included the Friends of the Royal Tasmanian Botanical Gardens Inc. and Hobart City Council. A successful joint application between RTBG, Queensland University, Parks and Wildlife Service and the Australian National Botanic Gardens was made to the Australian Research Council for a $300 000 SPIRT grant to conduct research on Subantarctic plants. Part of the research will be done in facilities at RTBG.

Funds from last year's extremely successful public appeal for funding (*The Mercury* Save the Gardens Appeal), which raised $220 000 have allowed considerable progress to be made in fighting the fungus *Armillaria luteobubalina*. This disease had infected 10% of the Gardens and threatened its survival. Funds were used for a series of major excavation of infected stumps and removal of infected non-essential trees. This strategy appears to have been successful, as there has been no recurrence to date of *Armillaria* fruiting bodies in the areas so treated.

A $40 000 grant under the National Estate Grants Program will allow the restoration of the Gardens historic 1845 sandstone gatehouse. This small cottage was the first project designed in Tasmania by William Porden Kay, the Government Architect who designed Government House. Work on the project began in December.

Acknowledgements

The Council is grateful for help generously given by many individuals and organisations throughout 1998. The lecturers, the Government of Tasmania, the University of Tasmania, Arts Tasmania, the Tasmanian Museum and Art Gallery are especially thanked for their support and cooperation. Thanks are also extended to CSIRO for use of the auditorium and conference rooms for public lectures and meetings, and to the catering staff for assistance with refreshments following meetings.

Dr S.W. Jeffrey AM, FAA
Vice-President

Dr A. Rozefelds
Hon. Secretary

4 February 1999

ROYAL SOCIETY OF TASMANIA

Statement of Receipts and Payments for the Year ending 31 December 1998

	1998 $	1997 $
Balance 1 January 1997	24 161.34	34 767.42
Add Receipts		
Subscriptions	8 882.50	11 170.00
Publications		
Regular sales	1 528.80	4 210.70
Rare book sale	–	11 620.00
ANZAAS related	–	2 931.64
	1 528.80	18 762.34
Donations		
Foundation	823.26	1 057.00
	823.26	1 057.00
Interest	110.47	233.66
State Government and University grants	7 100.00	8 000.00
Meeting funds		
Various functions	3 025.00	3 268.00
Sundry	81.10	343.22
	3 106.10	3 611.22
Student Bursary Collections	1 800.00	1 100.00
Total Receipts	23 351.13	43 924.22
Deduct Payments		
Subscriptions	2 530.87	3 818.19
Printing & stationery	2 424.23	2 238.60
Postal costs	2 691.90	2 977.04
Meetings attendants' fees	1 230.00	1 120.00
Functions	5 748.75	2 746.40
Bank charges	110.81	174.68
Publication costs	2 359.13	13 559.33
Northern Branch	–	5 000.00
Secretarial services	2 900.00	3 480.00
Administration/insurances	703.82	728.18
Sundry		
Repairs	–	126.55
ANZAAS	–	1 147.50
Other	2 212.40	433.00
Student support	1 500.00	1 000.00
Foundation/society advertising/promotion	1 468.95	2 034.53
Funds transfer	1 885.70	13 668.00
Sundry	45.29	278.30
Total Expenditure	27 811.85	54 530.30
Surplus (deficit) for the year	(4 460.72)	(10 606.08)
Cash at Bank Balance 31 December 1998	19 700.62	24 161.34

The accompanying notes form part of these financial statements.

Statement for the Royal Society Foundation Trust Fund for the Year ending 31 December 1998

Foundation approved by membership and Council 1995. Officially opened November 1995.

The Royal Society Foundation Trust Fund replaces all previous Trust and Memorial Funds. All funds held by Perpetual Trustees (as managers).

Funds held at 31 December 1997	46 072.10
Capital deposits during 1998	1 885.70
Total capital at 31 December 1998	47 957.80
Interest:	
Interest derived from capital fund 1998	2 023.56
Interest derived on interest fund 1998	277.77
Previous interest on funds	5 696.62
Total funds in Trust at 31 December 1998	55 955.75
Other information:	
Funds transferred in January 1999	823.00
Estimated value of Trust at date of AGM	57 000.00

Accumulation Account for the Period 1 January to 31 December 1998

Balance at 1 January 1998	$46 416.57
Balance adjusted - prev. uncashed chqs	1 147.50
	47 564.07
Cash items:	
Add increase at bank	(5 604.22)
less prior period outstanding deposit	(4.00)
	41 955.85
Asset acquisitions:	
Add new assets purchased during period	2 212.40
	44 168.25

Balance Sheet as at 31 December 1998

1997 $		1998 $
46 416.57	Accumulated Funds	44 168.25
51 768.72	Foundation Funds	55 955.75
7 004.77	Life Membership Fund	7 004.77
105 190.06		107 128.77
	Represented by	
51 768.72	General Account	19 700.62
35 097.69	Foundation Trust Perpetual Trust	55 955.75
15 000.00	Library (value for insur.)	15 000.00
5 000.00	Publications (est. realisable value)	5 000.00
5 600.00	Medals (at sell prices)	7 812.40
3 660.00	New Assets	3 660.00
105 190.06		107 128.77

ROYAL SOCIETY OF TASMANIA

Notes To and Forming Part of the Accounts for the Year ended 31 December 1998

Note 1 - Statement of Accounting Policies
This is not a general purpose financial report. It is a special purpose report prepared to meet the requirements of members of the Society.

The Society is of the type identified in Statement of Accounting Concepts 1 as a non-reporting entity. No regard has been paid to other Accounting Standards in the preparation of this report.

The accounts have been prepared on a cash basis from historical cost records, except where stated otherwise.

Income Tax
The Association is an exempt body for income tax purposes under Section 23(g)(iii) of the Income Tax Assessment Act.

Note 2 - Valuation and Existence of Assets
The insurance valuation for the library is only for petty theft. The actual value (in terms of net realisable value, cost, or market value) is not determinable. Therefore, the insured value of the library is not an accurate depiction of its value to the Society.

A number of paintings of considerable value exist that are the property of the Society. There are also a number of paintings which may be the property of the Society. These assets have been omitted from the Balance Sheet as their value cannot be accurately determined.

Independent Audit Report to the members of the Royal Society of Tasmania

Scope
We have audited the attached accounts of the Royal Society of Tasmania for the year ended 31st December, 1998. The Society's office bearers are responsible for the preparation and presentation of the accounts and the information they contain. We have conducted an independent audit of these accounts in order to express an opinion on them to the members of the Society.

Our audit has been conducted in accordance with Australian Auditing Standards to provide reasonable assurance as to whether the accounts are free of material misstatement. Our procedures included examination, on a test basis, of evidence supporting the amounts and other disclosures in the accounts, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion as to whether, in all material respects, the accounts are presented fairly.

As detailed in Note 1 to the Accounts, the Society is not a reporting entity because no users exist who are unable to command the preparation of reports tailored so as to satisfy specifically all of their information needs, and these Accounts are therefore "Special Purpose Financial Reports" that have been prepared solely to meet the requirements of the members of the Society.

The audit opinion expressed in this report has been formed on the above basis.

Qualification
As is common for organisations of this type, it is not practicable for the Royal Society of Tasmania to maintain an effective system of internal control over donations, subscriptions and other fund-raising activities until their initial entry in the accounting records. Accordingly, our audit in relation to fund-raising was limited to amounts recorded.

Audit Opinion
In our opinion, except for the effects of such adjustments, if any, as might have been determined to be necessary had the limitations discussed in the qualification paragraph not existed, the financial report presents fairly in accordance with the cash basis of accounting, as described above, the payments and receipts of the Royal Society of Tasmania for the year ended 31 December 1998 and its cash and bank balances as at that date.

DELOITTE TOUCHE TOHMATSU

L.T. COX
Partner
Chartered Accountant

Hobart, 3 March 1998

ROYAL SOCIETY OF TASMANIA – NORTHERN BRANCH

The statements for the Northern Branch were not examined by the Auditors but are included here for information.

Statements of Receipts and Expenditure for Year ended 31 December 1998

Balance 1 January 1998				3381.97
Receipts				
Trust Bank interest			2.85	
Payments				
Stationery	printing enevelopes	137.00		
	other stationery	123.40	260.40	
Postage	hire post box	44.00		
	postage	384.75	428.75	
AGM dinner guests' costs			141.00	
Suppers			85.45	
Secretarial honorarium			980.00	
Bank charges			3.10	1898.70
Net cash outflow				1895.85
Balance 31 December 1998				$1486.02

B.M. East
Treasurer, Northern Branch
Royal Society of Tasmania
2 March 1999

THE TASMANIAN LEGACY OF MAN AND FIRE

by W.D. Jackson

(with two tables, six text-figures and one plate)

JACKSON, W.D., 1999 (31:x): The Tasmanian legacy of man and fire. *Pap. Proc. R. Soc. Tasm.* 133(1): 1–14. ISSN 0080-4703. Department of Plant Science, University of Tasmania, GPO Box 252-55, Hobart, Tasmania, Australia 7001.

The vegetation of Tasmania is complex and much of it is in a state of disclimax. At the time of European settlement, the proportion of non-forest open vegetation was 37%, about 5% of this at high altitudes. In the present interglacial climate, in regions of high rainfall, where rainforest dominance might be expected, approximately 45% carries sedgeland, grassland, shrub communities and wet sclerophyll forest. Similarly, drier areas carry extensive grassland, sedgeland and heath, instead of dry eucalypt forest. This complexity of distribution and disclimax can be attributed to fire disturbance. Fire not only produces a successional mosaic but, through Ecological Drift, causes extinction of communities. This level of displacement appears to demand a timespan of human-induced fire sufficiently long to affect soil fertility. A palaeontological record of the last five glacial cycles has been analysed from the Darwin Crater in western Tasmania and compared with that from the Chatham Rise, New Zealand. These show parallel behaviour in the proportions of forest and non-forest communities in the earlier cycles. However, the Tasmanian record shows a marked divergence during the Last Glacial cycle, with a two-fold increase in open vegetation relative to closed forest. Eucalypt forest increases relative to rainforest, and charcoal increases relative to woody vegetation. These changes occur through a variety of climates, including full glacial and optimum interglacial, but are not apparent in the New Zealand core, making it difficult to attribute them to a climatic cause. In the Tasmanian vegetation, they can be explained by an increase in fire frequency, due to human activity. Since their onset occurs in isotopic oxygen stage 4 and continues in the differing climates thereafter, it may be inferred that the ^{14}C dates of the earliest evidence of occupation by the Aborigines are gross underestimates. A date of about 70 000 yrs BP is more likely. It appears that, when using ^{14}C methodology, such underestimation for dates beyond 30 000 yrs BP is to be expected in palaeosamples from western Tasmania.

Keywords: disclimax vegetation, fire, Aboriginal occupation, Tasmania.

INTRODUCTION

The Aborigines

Anthropological research shows that the Aborigines have occupied Tasmania since the Late Pleistocene. Rock shelter and cave sites, predominantly in limestone valleys across western and southern Tasmania, show occupation dating from 34 ka to about 12 ka (Cosgrove 1995: fig. 16). During this period of largely cool interstadial to cold glacial climates, the present eastern half of Tasmania was apparently too dry for Aboriginal food resources, although the now submerged continental shelf would probably have been extensively utilised. The precipitation of most of eastern Tasmania during the Last Glaciation has been estimated to have been 60% drier than the present 500–850 $mmyr^{-1}$ (Markgraf *et al.* 1986). Palaeontological and pedological evidence shows most of the eastern region to have had a dry-cold desert vegetation of Asteraceae-Chenopodiaceae shrub steppe, with few trees, shifting sand dunes and dry watercourses (Bowden 1983, Sigleo & Colhoun 1981, 1982, Colhoun 1977, Nicolls 1958). In contrast to the lack of evidence for Aboriginal occupation of the eastern region before 12 ka, this region shows abundant evidence of extensive use from early in the Holocene up to the time of European settlement. However, the sites previously occupied in the western region were abandoned and not reoccupied after the beginning of the Holocene.

It appears that the Aboriginal population was not large. Estimates range from one to several thousand (Ling-Roth 1899: 113, Milligan 1858). Most estimates were probably exaggerated because the Europeans only had contact with the Aborigines in the east and on the coasts, where their population was densest.

The information gathered early in European settlement indicated that small family groups operated independently, hunting and food gathering in a truly nomadic fashion with extensive home ranges of about 70 km (La Billardiere 1800, Ling-Roth 1899). While on the move, they carried fire in the form of smouldering decayed wood or fungus (Ling-Roth 1899; see pl. 1). As a consequence, the vegetation was frequently ignited by accidentally dropped embers.

The Aborigines used fire extensively as a tool, to advertise their presence to others, to flush animals out of cover, to combat enemies and to systematically burn patches of vegetation in a controlled manner to create "green pick" grazing for herbivores, thus ensuring future hunting success. Wet closed forests provided few resources and were avoided, although some so-called "native roads" through forest (Robinson in Plomley 1966) were kept open to provide access to hunting grounds. As a consequence of its extensive forested regions, western Tasmania, apart from the coastal fringes, received little use by the Aborigines during the Holocene, and the large expanse of sedgeland in the inland southwest was also sparingly utilised, presumably because of the low animal productivity.

The Environment

General short descriptions of the Tasmanian environment are available (Jackson 1981a, 1998b). The factors which control the interactions of fire and vegetation may differ from those pertaining to mainland Australia and, therefore, are described here.

The climate of Tasmania is dominated by its position at latitude 40°–43°S on the northern edge of the southern zonal wind system, the Roaring Forties. Since only about

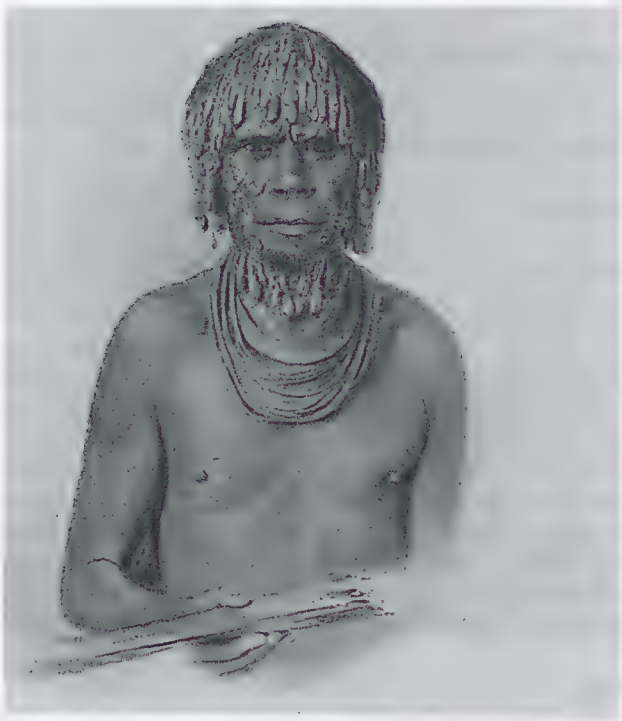


PLATE 1
A Tasmanian Aborigine holding a fire stick (after Bock) (Ling-Roth 1899)

4% of the Earth's surface at this latitude is land, the lack of continentality provides a strong and dependable marine influence. By Northern Hemisphere standards, the seasons are merely an alternation of extended spring and autumn. As a result of the strong westerly bias in the wind impinging on the mountainous terrain in the western and northeastern regions (which present altitudes of 900–1500 m), there is a strong gradient in precipitation from 1500–3000 $mmyr^{-1}$ in the west to <500–850 $mmyr^{-1}$ in the east (fig. 1). Reliability is high in the west, deviating only <10–14% from the mean average, while in the eastern half deviations of 16–>20% are found (Scott 1956). Due to the seasonal movement of the belt of zonal wind, the northwestern quarter tends to partially escape this in summer–autumn, so that a two-season dry, two-season wet pattern develops, with about 50% of the seasonal divergence common to southeastern Australia. In the southwestern quarter, there is a marked movement to a uniform seasonal distribution, with only summer showing a 5% deviation (Jackson 1998b).

Evapotranspiration levels in the eastern half are high, due to the windy environment and high radiation load (Nunez 1978). The aspect effect is very strong in Tasmania, due to the latitude. Holland & Steyn (1975) estimated the difference in radiation levels between equatorial and polar-facing slopes of 30° to be equivalent to a shift of 20° in latitude. This effect contributes much to the mosaic distribution of vegetation types and the incidence of fire. Precipitation/evaporation ratios range from 4:1 in the west to <0.5 in the east. Through the marine influence, permanent snow does not exist and snow lie is ephemeral. Extended periods of low temperature are rare, even on the considerable areas (~5%) of inland high country between 800 and 1200 m. As a result, a treeline is difficult to define at any one altitude, and trees (especially rainforest spp.) ascend to altitudes >1000 m, gradually assuming shrubby forms. Inverted treelines occur inland largely due to the combined influences of fire and frost.

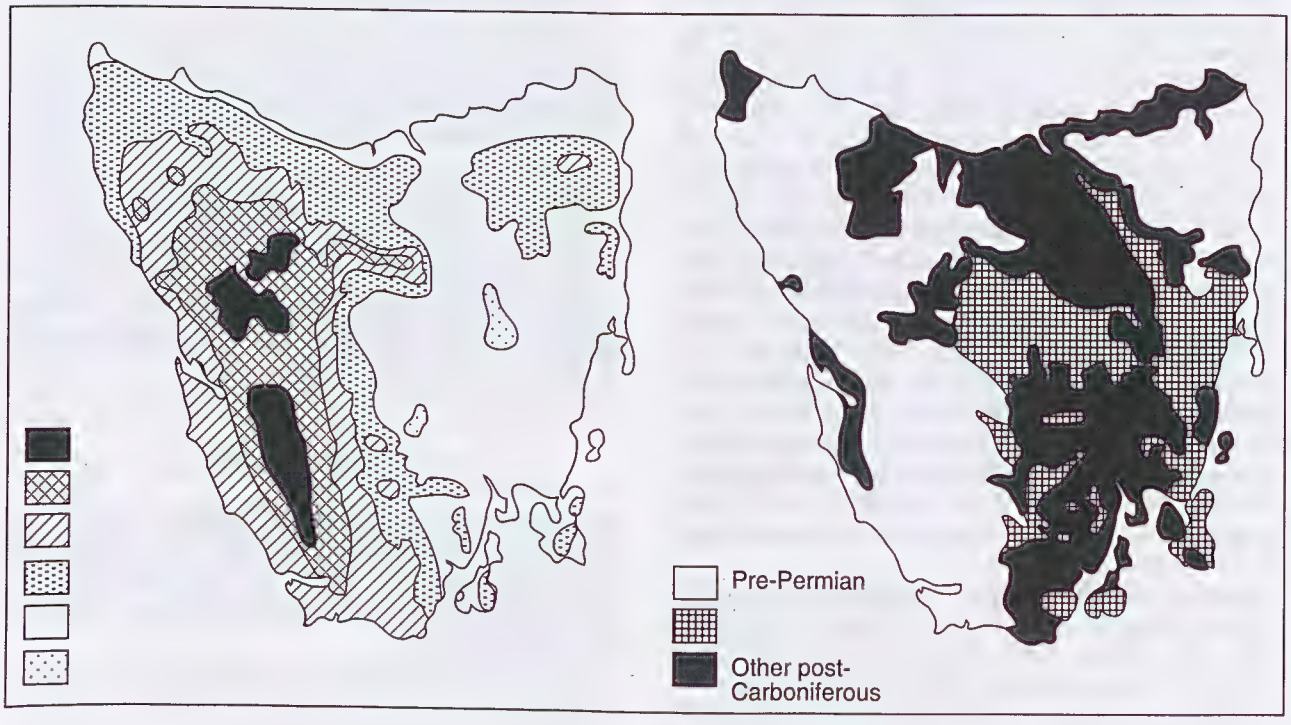


FIG. 1 — The general pattern of precipitation and geological exposure simplified from several sources.

ROYAL SOCIETY OF TASMANIA
Papers and Proceedings
Volume 133, Part 1
ERRATUM

The loss of some text within Figure 1 on page 2, present in an early proof, was not detected prior to printing.
Herewith a correct version of the figure.
M.R. Banks, Hon. Editor

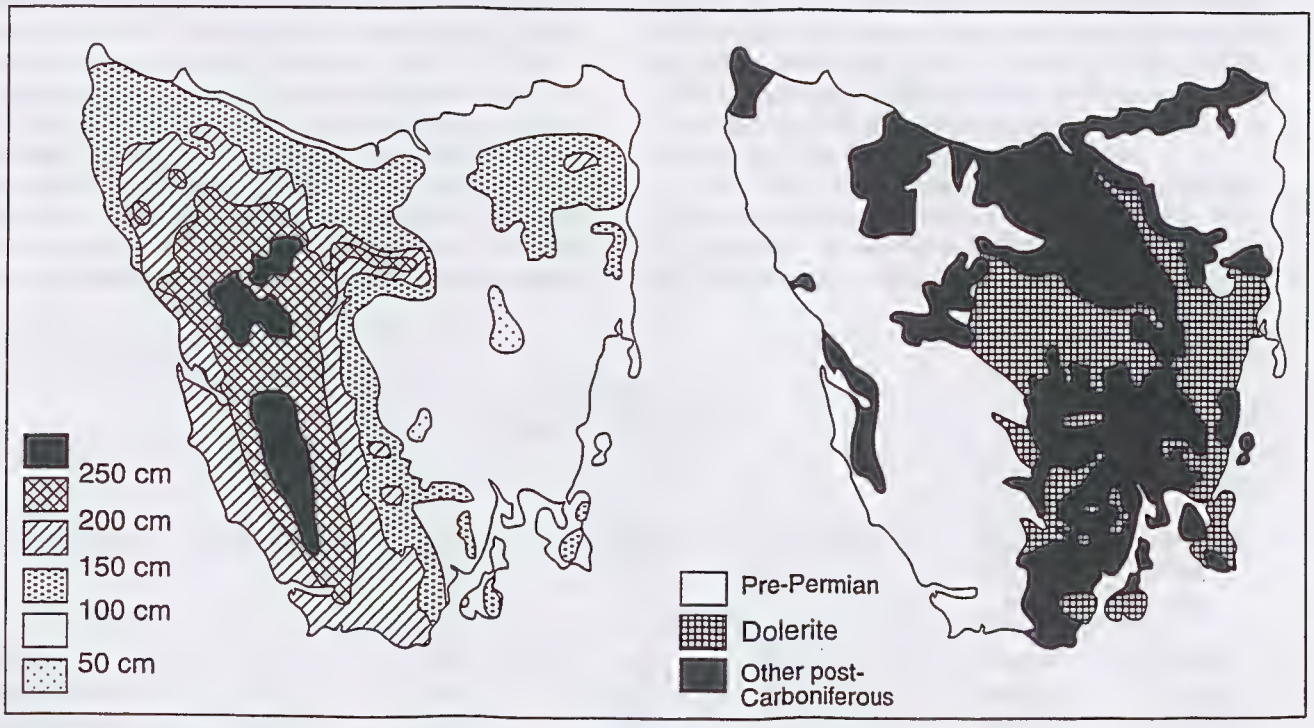


FIG. 1 — The general pattern of precipitation and geological exposure simplified from several sources.

The annual weather pattern is dominated mostly by a succession of cold fronts embedded in the westerly air stream, bringing rapidly fluctuating temperature and precipitation. Fronts move rapidly, often more than 1000 km day^{-1}, transverse to the strong pressure gradients which occur between the slow-moving cells of high pressure, usually centred over middle Australia, and the rapidly moving low-pressure cells of the high 40°S latitudes. In summer, during February–March, when the zonal belt moves south, high-pressure cells are occasionally centred just east of Tasmania; approaching cold fronts cause high-pressure gradients, bringing strong winds of very hot, dry air from inland Australia. This causes extreme fire danger conditions: maximum temperatures 37°C, relative humidity <10%, average wind speed 50+ km hr^{-1}, maximum gusts >95 km hr^{-1}, equivalent to drought factor 9. Such conditions generally occur for one or two days each summer, usually producing a rash of forest wildfires. However, when the vegetation is already in a state of drought, very serious wildfires occur. Such recurrent drought conditions appear to be based on an 11-year cycle. This pattern is disturbed by the El Nino southern circulation effect, which appears to move the belt of zonal winds further south (Jackson 1999b), reducing the strength of the westerly stream.

The incidence of fire in Tasmania is overwhelmingly due to human activity. Lightning-induced fire is rare, unlike in mainland Australia. An analysis of the wildfire records shows that the incidence of fire resulting from lightning strikes is very small (0.01–0.1% of cases) and the area thus burnt is also comparatively small (<0.01% of the total), since rain usually accompanies electrical storms in Tasmania (Jackson & Bowman 1982, Ingles 1985). Many fires are already burning when the extreme fire danger conditions arise.

Once a forest fire in Tasmania gains a sufficient front in severe conditions, the fire storm creates strong convection updrafts, which carry burning bark and branches to high altitudes. Burning embers carried downwind create a contagion of spot fires for distances of up to 60 km (Cheney 1981). A detailed analysis of past fires based on records and on tree ages (Marsden-Smedley 1998a, b) shows that severe fires have occurred more than six times in the last 200 years. Two of these fires, in 1898/99 and 1933/34, each burnt 15 to 20% of the island.

VEGETATION

Fire and Geological Influences

The current vegetation of Tasmania has been accurately mapped (Kirkpatrick & Dickinson 1984, R.F.A. 1996). Figure 2 provides a simplified version of Kirkpatrick and Dickinson's map (Duncan 1990). Short descriptions of the vegetation types were given by Jackson (1965, 1981b, 1999a) and detailed studies provided in (Reid *et al.* 1999). The following notes deal with those aspects important to an appreciation of past and present effects of fire.

Table 1 shows the relative areas of the major vegetation types: the proportion estimated to have existed in 1800, the proportion at present, and those for the northwestern and southwestern quarters, the average fire-free interval

TABLE 1
Major vegetation types

1	2	3	4	5	6	7
vegetation type	pre-European* %	present† %	northwest‡ %	southwest§ %	fire-free interval¥ yrs	combustible fuel¶ t/ha
rainforest	9.8	8.5	26.2	19.5	150–300	25–30
swamp forest	0.6	0.2	0.2	–	100–200	20–30
wet sclerophyll	19.2	14.6	24.9	15.7	80–150	180–320
dry sclerophyll	43.1	23.1	2.1	–	20–80	20–30
grassland	1.3	0.8	1.1	–	10–25	4–8
heathland	6.4	3.4	1	–	10–30	10–20
alpine	1.7	1.7	3.2	4	100–250	10–15
saltmarsh	0.06	0.05	–	–	∞	–
wetland	0.4	0.2	–	–	40–80	2–4
sedgeland	17.4	17.2	27.4	56.2	20–40	10–30
total %	100	70	86.2	95.4		
cleared land %	–	30	13.8	4.6		
area, millions ha	6.62	6.62	1.34	1.23		

* Estimated relative to the whole state of Tasmania (Kirkpatrick et al. 1995). The figure quoted for dry sclerophyll included large areas which, in 1804, were open grassland or open savannah.
† Relative to whole state (Kirkpatrick et al. 1995).
‡ West of Forth River to Mt Manfred (estimate from Kirkpatrick & Dickinson 1984).
§ Protected region (modified after Marsden-Smedley 1998, after allowance for impoundments and roads).
¥ Average interval between consecutive fires (Jackson 1968).
¶ Average quantity of combustible fuel at time burnt (compiled from a number of sources).

and the average combustible fuel load when burnt by wildfire.

The essential proportional distribution of these vegetation types has suffered little change since European settlement (table 1). When the free settlers arrived, they found the eastern half of the island with extensive open savannah grassland tracts in the Midland graben and other major valley systems. These tracts were rapidly taken up, since little or no clearing was necessary to start a grazing enterprise. It is clear that the openness of the vegetation was the product of patch-burning by the Aborigines (Jackson 1965, Fensham 1989). The western half of Tasmania, with its dense forests and peaty sedgelands, was left untouched by early settlers except for the exploitation of Huon Pine at Port Davey and Macquarie Harbour. The Van Diemans Land Company made an attempt to utilise the grasslands developed by the Aborigines in the wetter regions of the northwest, but this was not successful, due to the cold, wet climate.

This denser forested region in the west was not opened up until after 1870, when mineral discoveries due to prospecting initiated extensive firing of the vegetation. Land clearing of the productive soils in the northwest occurred late in the 1800s with the use of ringbarking and fire. The present extent of cleared land (30%) was taken mainly at the expense of eucalypt forest along the northern hinterland in the early 1900s, following very extensive wildfire in 1898/99.

The proportionate differences in the distribution of vegetation types in regions is not merely a response to precipitation (fig. 1). Although the eastern half is much drier and contains virtually all of the dry sclerophyll forest and most of the grassland and heaths, it has withstood the constant firing practices of the Aborigines during the Holocene remarkably well. This can be attributed to the fire-tolerant attributes of the sclerophyll species, especially the eucalypts, and to the clay-rich soils of most of the region. Sills of dolerite cap most of the topographic high points in post-Carboniferous rocks of the eastern half. The dissemination of clay-forming minerals from the dolerite by erosional forces has resulted in soils with a moderate to high cation-exchange capacity. This buffers many soils in the region against leaching losses after fire (Boerner 1982).

Although the western half has been little utilised in the Holocene by the Aborigines, the vegetation appears to show far greater effects of modification by fire, particularly in the southwestern quarter. The considerable differences in the proportionate distributions between the southwestern and northwestern quarters (table 1), although they both receive similar precipitation levels, can be attributed to geological influences in soil genesis. While most of the western region has pre-Carboniferous rocks exposed, the elevated plateau region north of the Pieman River carries remnants of a thin Tertiary basalt cover over much of the highly quartzose Precambrian metamorphic sediments. Erosional processes have distributed the clay-forming minerals from this basalt, from the dolerite on the western fringe of the Central Plateau to the east, and from Cambrian volcanic exposures. As a consequence, most of the valleys here have moderately fertile soil compared to the southwest, with a cation-exchange capacity sufficiently high to resist leaching following fire. The regions with a residual basaltic cover carry krasnozem soils and support extensive forests of callidendrous, tall, closed canopy *Nothofagus* rainforest (Jarman & Brown 1983, Jackson 1983). Exposures of Precambrian quartzitic sediments and some highly quartzose Cambrian sediments have infertile soils supporting implicate or broken canopy rainforest, scrub and sedgeland.

There are few sources of clay minerals in the southwest. The predominant geological exposure is of highly quartzose, metamorphic Precambian sediments. Smaller regions of Cambrian, Ordovician and Devonian-Silurian rocks occur in anticlines, where limestone and sandstone are often covered with quartzitic glacial till and outwash gravels.

The soils of the southwest are, in general, acid and highly organic with a low cation-exchange capacity (Maclean 1979, Bowman *et al.* 1986). Very few patches of tall, wet forest exist, reflecting the general low level of fertility. A few patches of climax callidendrous rainforest occur in the Boyd River catchment on aspects highly protected from fire, even on Cambrian quartzwacke sediments with no clay in the soil profile. It is certain that such patches have not been burnt for well over 500 years. The biomass has apparently been developed on accumulated nutrients derived from cyclic salt in the precipitation, demonstrating that the climatic climax can be achieved, albeit rarely, on extremely infertile geological substrate, provided that fire does not occur (Harwood 1972, Jackson 1977). Most rainforest in the southwestern quarter is implicate or broken canopy forest (Jarman & Brown 1983, Jackson 1983) and demonstrates signs of fire disturbance. The wet sclerophyll forests in the southwest are predominantly *Eucalyptus nitida* wet mallee woodlands rather than forests. Probably only about 20% of the wet sclerophyll is tall forest occurring on fire-protected polar aspects.

The predominant vegetation in the southwest, especially on Precambrian quartzites, is a sedgeland heath dominated by *Gymnoschoenus sphaerocephalus* with mosaic patches of wet scrub of *Leptospermum/Bauera/Agastachys* on water courses and other fire-protected habitats. The soils, although highly organic muck peats, are extremely infertile, with cation-exchange capacities <20% (Maclean 1979, Bowman *et al.* 1986). The low fertility is maintained by the average short fire-free interval of 25–40 years over the southwestern region.

The Disclimax State

As the vegetation map (fig. 2) demonstrates, the distribution of the vegetation is a complex mosaic of community types. The almost complete dominance of all but the most alpine sites by forests, as expected on the basis of a climatic climax for such an insular climate, does not occur. In contrast with this expectation, much of Tasmania carries a mosaic of disclimax vegetation, with extensive areas of grassland, sedgeland, heath and scrub. Also, large areas of forest dominated by eucalypts occur in environments which climatically should be the exclusive domain of rainforest.

The amount of open, non-forest land appears to be inexplicably high, given the levels of natural wildfire. The proportion of open, non-forest vegetation existing in 1800 has been estimated (table 1) by adjusting the present distribution of vegetation types on the basis of historical records of land acquisition and clearing (Kirkpatrick *et al.* 1995). This shows that, at the time of European settlement, the proportion of open, non-forest vegetation was about 37%; of this about 5% occurred in alpine or high plateau regions (table 1).

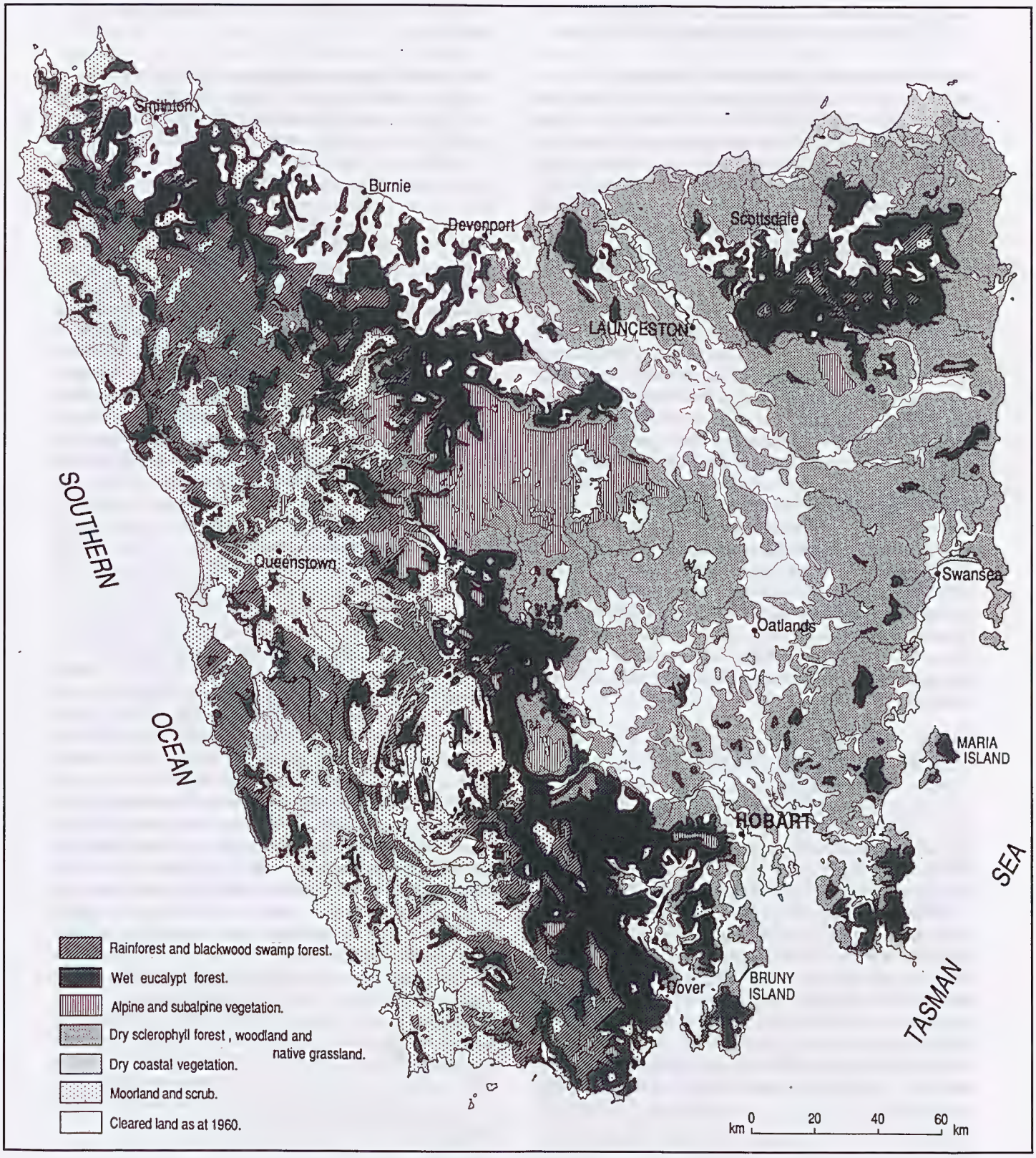


FIG. 2 — The vegetation, simplified after Kirkpatrick & Dickinson (1984) by Duncan (1990).

A few regions where the vegetation is climax or nearly so show every indication of having recently reached that state; for example, the forests of the lower Florentine Valley before 1934 (Gilbert 1959) and the absence of old trees in closed *Nothofagus* forests on the Guildford Plateau (Jackson 1965). These young forests generally only occur on good, productive soils and/or where their protected location limits the frequency of fires (Jackson 1965). They appear to have colonised previous grassland since European settlement.

This disclimax condition is not entirely due to our present exploitive society, as it was evident before European settlement. In the absence of fire produced by humans, a very different pattern of vegetation would have existed, as the following outline suggests.

A Hypothetical Distribution of Vegetation for the Holocene in the Absence of Humans

High rainfall regions (precipitation > 1200 mmyr^{-1})

In those regions where precipitation exceeds 1200 mm per annum, over 40% of the area, at the time of European settlement, carried disclimax vegetation such as grassland, sedgeland, heath, scrub and eucalypt forest, although most of the latter was mixed with *Nothofagus* (Jackson 1968, Brown & Podger 1982a). The climax vegetation expected on all aspects and in all but the most extreme alpine habitats would be *Nothofagus* rainforest. This is demonstrated by the rapid capture of *Poa* grassland communities on the Guildford Plateau by *Nothofagus* (Jackson 1965); the demise of eucalypt communities on the northeastern highlands (Jackson 1968, Ellis 1986) following their rapid invasion by *Nothofagus* forest; the successional movements to rainforest, even on soils of low nutritional status (Brown & Podger 1982b); the presence of patches of callidendrous rainforest in the upper Boyd river catchment, growing on extremely infertile Cambrian quartzwacke sediments and apparently totally dependent on cyclic salt input (Harwood 1972, Jackson 1977). In this hypothetical state, there would be some lightning-induced fires destroying patches of forest. However, the *Nothofagus* dominance in these burnt patches would return in one generation of the seral forest tree *Acacia melanoxylon* which has a lifespan of 90–110 years (Gilbert 1959). Since the prevalence of lightning-induced fires is very small in Tasmania (0.6% incidence and 0.01% in area in comparison with man-made fire at present — Jackson & Bowman 1982, Ingles 1985), the amount of disclimax vegetation would have been insignificant in the absence of mankind.

Medium rainfall regions (precipitation 800–1200 mmyr^{-1})

In the marginal regions of precipitation, for tall, closed wet forests, two distinct forest communities would prevail, due to the light limitation of the seedling stages of sclerophyll communities and the water limitation of rainforest regeneration (Read 1985, Jackson 1981c, Jackson & Brown 1999). Their distribution would be dictated by the very strong aspect effect (Holland & Steyn 1975).

The present intergrading of many vegetation types would not occur. In the absence of frequent fires, the boundaries between the *Nothofagus*-dominated rainforest communities on the polar aspects and the *Eucalyptus*-dominated sclerophyll communities on the equatorial aspects would be sharp without much intergradation. This is determined by the requirements of the seedling stages of the two communities. Sclerophyll seedlings cannot tolerate the shade cast by *Nothofagus* communities, and *Nothofagus* communities are unable to compete with eucalypts and other sclerophylls under the conditions of limited water availability on equatorial-facing aspects (Read 1985, Jackson 1981c, Jackson & Brown 1999). Therefore, in the absence of frequent fires, the boundaries between the communities would be sharp and the present intergrading would not occur. Since eucalypts require fire disturbance at intervals throughout their lifespan (maximum 300 years) the extensive forests of wet sclerophyll seen today in regions with precipitation 1000–1500 mm would be replaced by closed *Nothofagus* rainforest (Jackson 1981b, Jackson & Brown 1968). The probabilistic argument of the Ecological Drift theory (Jackson 1968) suggests that eucalypts could not survive long-term in such conditions without man-made fire.

Low rainfall regions (precipitation < 500–850 mmyr^{-1})

In the low-rainfall regions of the east, the vegetation would be an almost complete forest cover of sclerophyll. Evidence for this derives from the successional stages following fire.

Eucalypts are highly adapted to fire and, in habitats where rainforest species are restricted by the availability of water, continuous regeneration of eucalypts is always possible, due to the availability of light for seedling growth (Read 1985). A number of species have evolved within the genus, each having a competitive advantage in particular environmental niches of water availability, drainage, nutrition, frost etc. (Reid & Potts 1999). For example, the savannah grasslands of the Midlands region were clearly a product of burning practices by the Aborigines (Fensham 1989). Extensive regions on both margins of these communities have been captured by pole stands of open eucalypt forest since European settlement (Duncan 1990, Jackson & Brown 1999). Frost and grazing pressures slow the encroach of forest, but it is clear from the relationship of forest type to the dryness index that forest will prevail (Nunez 1978). Narrow corridors of rainforest communities would exist in gullies and in very protected polar-facing aspects, largely dominated by *Atherosperma*, although some areas of *Nothofagus* dominance would occur. For example, a number of patches of rainforest occur in regions of Tasmania with annual precipitation less than 800 mm. All are on fire-protected southeastern aspects, such as Kempton Tier (annual precipitation P = 505 mm), Dromedary (P = 665), Maria Island (P = 656) and Lake Leake (P = 800). Extensive gully communities of *Olearia* and *Bedfordia* would extend to the coastal fringe (Jackson 1983). The general cover in the areas with rainfalls less than about 800 mm would be eucalypt forest, which would be far more uniform than at present in terms of species distribution and age structure. With very low fire-frequencies, none of the present patchwork of open or semi-open communities, such as heath, sedgeland and grassland savannah, would exist. The present survival of heaths is due to the high rate of firing in these communities (Jackson 1968). Most occur on sandy or duplex soils, where nutrition is limited and other conditions, such as drainage, often contribute to slow growth-rates of woody plants. The frequency of fire increases the leaching and prevents the accumulation of nutrients, maintaining a cycle of early successional stages.

Various alternatives to the universal dominance by *Eucalyptus* species in the near absence of fire have been suggested (Withers & Ashton 1977). It is probable that, in the virtual absence of fire, in some regions *Allocasuarina* forests would dominate and *Callitris* in others (Brown & Bayly Stark 1979, Harris & Kirkpatrick 1991).

Open areas

The open grassland savannah of the Midlands and other larger valley systems was a product of high fire-frequency imposed by the Aborigines (Jackson 1965, Fensham 1989), as was the higher altitude grassland on the Middlesex–Hampshire and Mathinna plains. It is incorrect to attribute the openness of these and other areas to European development (Jackson 1965, 1981a, Bowman & Brown 1986, Ellis 1986). Hellyer in 1827, reporting on the country around Valentines Peak (Bishoff 1832), stated:

> Fine open country to NE and SW — grassy hills and knolls 1000–1500 acres in a patch and without a tree except for a few clumps of Blackwood — kangaroo were here in abundance as in every part of the country about — proceeding SW passed through excellent country consisting of gently rising, dry grassy hills. On the following day walked over many considerable hills the grass of which had recently been burned by the natives.

ECOLOGICAL DRIFT

It has previously been argued (Jackson 1968) that the disclimax state of the vegetation is the product of a long history of recurrent fire produced by human activity. Jackson proposed that

- complex interactions between vegetation, soil and fire vie with climate in controlling the genesis of both soil and vegetation (fig. 3B);
- variation in the interval between two successive fires, by interruption of regenerative processes described by Noble & Slatyer (1981) as a disruption of the flow of vital attributes, could produce sudden changes in the type of vegetation;
- each community type has a statistically variable distribution of the fire-free interval, ranging in central tendency, variance and skewness;
- reproductive cycles of characteristic species could be terminated by fires at large deviations from the central tendency.

The continuance or otherwise of mixed forest (Gilbert 1959), where an open stratum of tall, wet sclerophyll eucalypts stands over a closed canopy of rainforest, will illustrate these processes.

The first fire kills all trees. Both eucalypts and rainforest regenerate from seed. The original eucalypt regeneration reproduces after about 20 years.

(1) If the second fire occurs before about 20 years, all trees are eliminated and the forest is replaced by seral open vegetation of herbs, sedges and ferns.

(2) If the second fire occurs between 20 and 40 years, rainforest species will be eliminated and the mixed forest reverts to wet sclerophyll forest.

(3) Fire after the rainforest has matured regenerates mixed forest.

(4) If the period between the two fires exceeds about 350 years, the eucalypts will be eliminated, because eucalypt seedlings cannot survive in the low light intensity under the rainforest canopy. As a result, the mixed forest is converted to pure rainforest.

The process was termed "Ecological Drift" because of its similarity to genetic drift. Empirical distributions for the probability of the fire-free interval for the various types of vegetation were determined by the assessment of plant age on a large number of sites. These are shown in figure 3A with the projected drift movements. The process of drift is reversed by normal successional processes. However, there are obvious trends towards communities with vegetative means of reproduction, which can tolerate short fire-free intervals. These can increase the probability of "sinks", if soil fertility is also decreased by leaching or volatile loss after fire.

It is not possible to show experimentally the validity of the Drift argument. The boundaries between vegetation types at present seem remarkably stable. Even after extensive wildfire, most communities re-established on their original habitat with but minor boundary changes. The apparent stability of these boundaries led Mount (1979, 1982) to propose a theory of "Stable Fire Cycles". In contrast to the Ecological Drift concept, the Stable Fire Cycle theory assumes that the incidence of fire in a community is almost constant, because it is dependent on the particular rate of fuel accumulation of the community (table 1), and that the possibility of ignition is almost constant. The incidence then depends on sufficient fuel accumulation.

Much debate has taken place regarding the relative validity of the two theories (Macphail 1980, Bowman & Jackson 1981, Mount 1982, Jackson & Bowman 1982). Markov simulations by Henderson & Wilkins (1975) and later adjustments (Brown & Podger 1982b) supported the projections of the Ecological Drift theory. The intervals between fires in five structural forms of vegetation at Bathurst Harbour and at Hogs Back in the Lune River catchment are in broad agreement with the predictions of the Ecological Drift model. Recurrent fires by Europeans have converted implicate rainforest to *Gymnoschoenus* sedgeland at Hogs Back in <100 years (Brown & Podger 1982a, c, Podger *et al.* 1989).

The Ecological Drift paper (Jackson 1968) was written when the accepted period of human occupation of Tasmania was 10–12 k yrs. The present history of occupation, extending to at least 34 ka (Cosgrove 1995: fig. 16), makes the Drift argument more credible. However, because of the apparent static nature of the community boundaries at present, it is still difficult to understand how such extensive areas of disclimax vegetation could arise in even 34 k yrs. Changes to the physical structure of the soil and its fertility seem even less likely to have occurred within this timespan.

GEOLOGICAL EVIDENCE

Palaeoclimates

The past oscillating sequences of climates during the Quaternary (Colhoun & Fitzsimons 1990, Kiernan 1989, Jackson 1999c) have resulted in corresponding sequences of vegetation change, as treelines shifted up and down 1000 m in altitude, and cold, arid shrub steppe-grasslands alternated with humid forests (Macphail 1979, Kirkpatrick 1986, Jackson 1999c). It is apparent that the altitude range and rugged topography, plus the availability of a wide continental shelf and bridging connection to mainland Australia, permitted refuges for species in most climates, humid or arid, warm or cold. Each climate soon established a stable vegetation, due to the persistence of species but not communities, through change.

The length and intensity of the glacial–interglacial episodes differed, presumably due to interaction between the various components responsible for orbital forcing. Temperature and precipitation varied sufficiently to produce differing vegetation responses in both glacial and interglacial climates. Each period of rapidly changing climate produced equally rapid changes in vegetation, resulting in restructured plant communities. Based on analysis of pollen diagrams of the last four glacial cycles (350 k yrs) from the Darwin Crater (Colhoun & Van de Geer 1988, 1998, Colhoun 1989), the estimated average response time of the vegetation to a full transition of the climate from glacial to interglacial conditions is about 2.7 k yrs; the response time of the

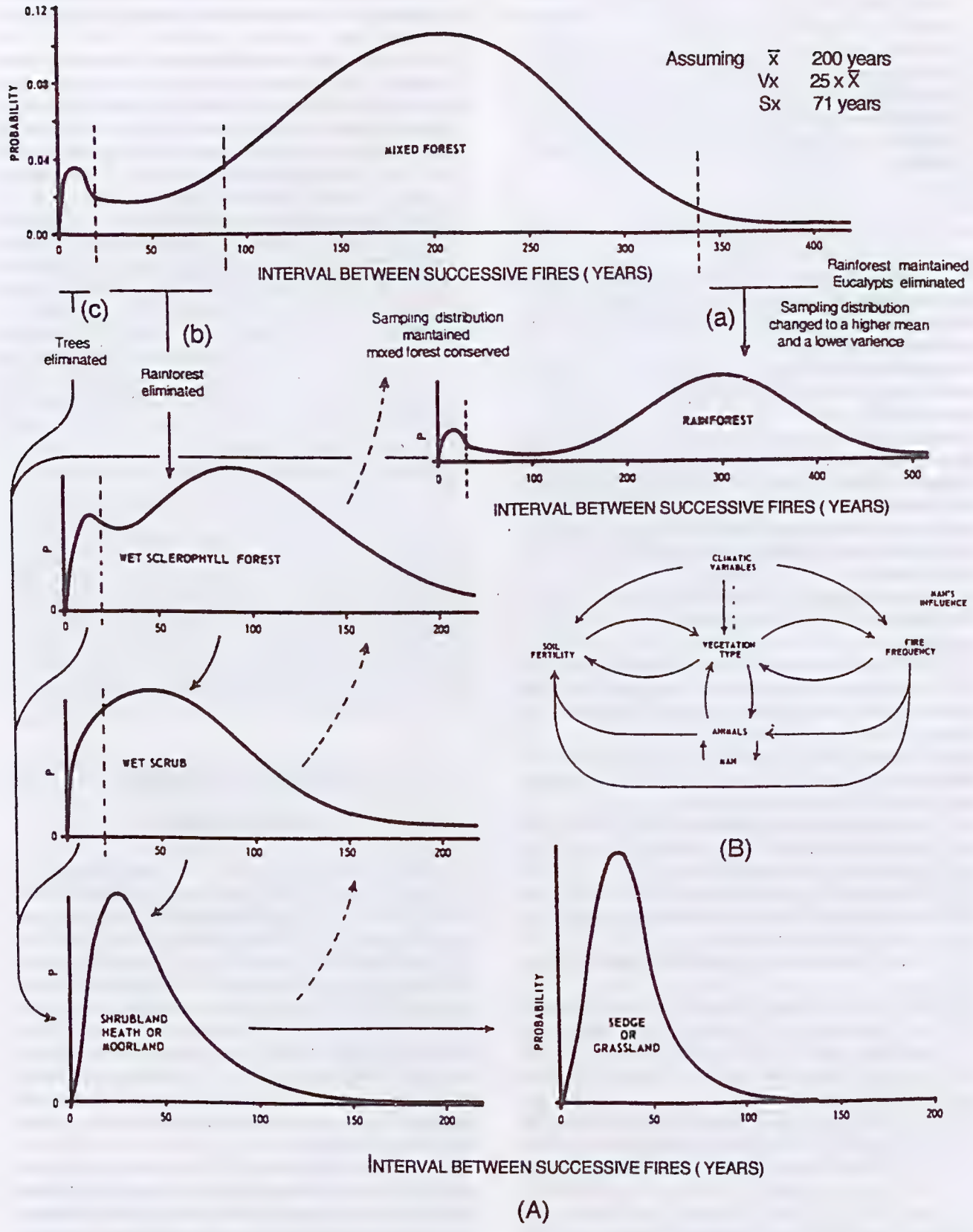


FIG. 3 — (A) Ecological Drift, a diagrammatic interpretation of progressive shifts in likelihood of vegetation types and their associated fire frequencies. It is assumed that drift in the sampling distribution occurs through chance occurrences of short or long intervals between two successive fires. Broken arrows indicate long-term climatic succession. Chance long intervals (>300 yrs) lead to the elimination of eucalypts. This causes a lowering of the fire risk in future generations of forest (a). Chance short intervals (20–40 yrs) lead to the elimination of rainforest (b), or (if <20 yrs) of all forest species (c), with a consequent shift to sampling distributions with lower mean fire-free intervals. This increases the probability of drift to degraded open vegetation with a high fire frequency, a process which is accelerated on poor soils because of vegetation–fire interactions with associated increased loss of nutrients through sublimation and leaching. (B) Vegetation–fire–soil interactions and human input.

reverse change from interglacial to glacial is marginally shorter at about 2.5 k yrs. About 80% of the transition occurs in less than 20% of these full transition times, i.e. in 500–600 yrs. This would approximate two generations of dominant trees. The early periods almost certainly produced bursts of evolutionary activity, extinction of species and emergent new forms.

The varied pattern of climate in Tasmania over the later Quaternary, as reflected in the vegetation, is illustrated by the pollen profile from the Darwin Crater in the Andrew River valley, western Tasmania (42°19'S, 145°39'E, 180 m a.s.l.). This crater was formed by a meteorite impact (Ford 1972) c. 700 ka (Gentner *et al.* 1973, Fudali & Ford 1979). The subsequent lake has been infilled by sediment from surrounding forests (Colhoun & van de Geer 1988, 1998, Colhoun 1989). The provisional summary of the upper 20 m of this core of 63 m depth (Colhoun & van de Geer 1998) is reproduced in figure 4A, where the pollen sums of the major categories of rainforest, trees and shrubs, and alpine shrubs and herbs are shown as a percentage of the total pollen sum. Aquatic and swamp taxa have been excluded from this sum. The sums were obtained from the analysis of pollen in samples from 100 mm long consecutive sections of the core in depth. There are, unfortunately, four breaks in the core, one of which removes much of the evidence in the last interglacial. On the basis of the relative proportions of the major categories of the vegetation, Colhoun & van de Geer (1988) divided this 20 m section of the core into ten zones of inferred climate corresponding to the oxygen isotope stages, showing five cold, dry and five warm, wet periods. The diagram illustrates the repeated pattern of forest expansion and contraction, typifying the major zones. It also demonstrates the variability within each major zone, as typified by the subzones defined by Colhoun & van de Geer (1998).

A deep-sea sediment core taken on the Chatham Rise, 250 km off the east coast of the South Island of New Zealand (Site DSDP 594, at 45°31'S, 174°56'E) at a comparable latitude to the Darwin Crater (42°S), has been analysed by Heusser & van de Geer (1994). The pollen sum for the top 40 m of this core fortunately covers the same region of the oxygen-isotope scale and, thus, provides a comparison with that of the Darwin Crater.

The sediment on the Chatham Rise is predominantly from river transport and, therefore, the depths of core corresponding to the stages of the oxygen-isotope scale are quite different from those of the Darwin Crater. The New Zealand data are plotted in figure 4B on the same scale and using the same procedures as those used to develop figure 4A, except for the above differences in the length of the zone sediments.

Figure 4A and B summarises the percentages of pollen of taxa forming open vegetation (grassland, sedgeland and heath) as distinct from closed forest taxa in the total pollen sums. Both cores have been divided into zones corresponding to the oxygen isotope stages, on the basis of the relative proportions of the major vegetation types of forest and open vegetation. The zones shown in figure 4A and B correspond to the stages of the isotopic oxygen deficiency established for the Chatham Rise site (fig. 4C; Nelson *et al.* 1986).

The correspondence in the Darwin Crater Core between palaeovegetation zones and isotopic oxygen deficit stages is shown in figure 4A. On this basis, the correspondence between the stages in the Darwin Crater core (A) and the

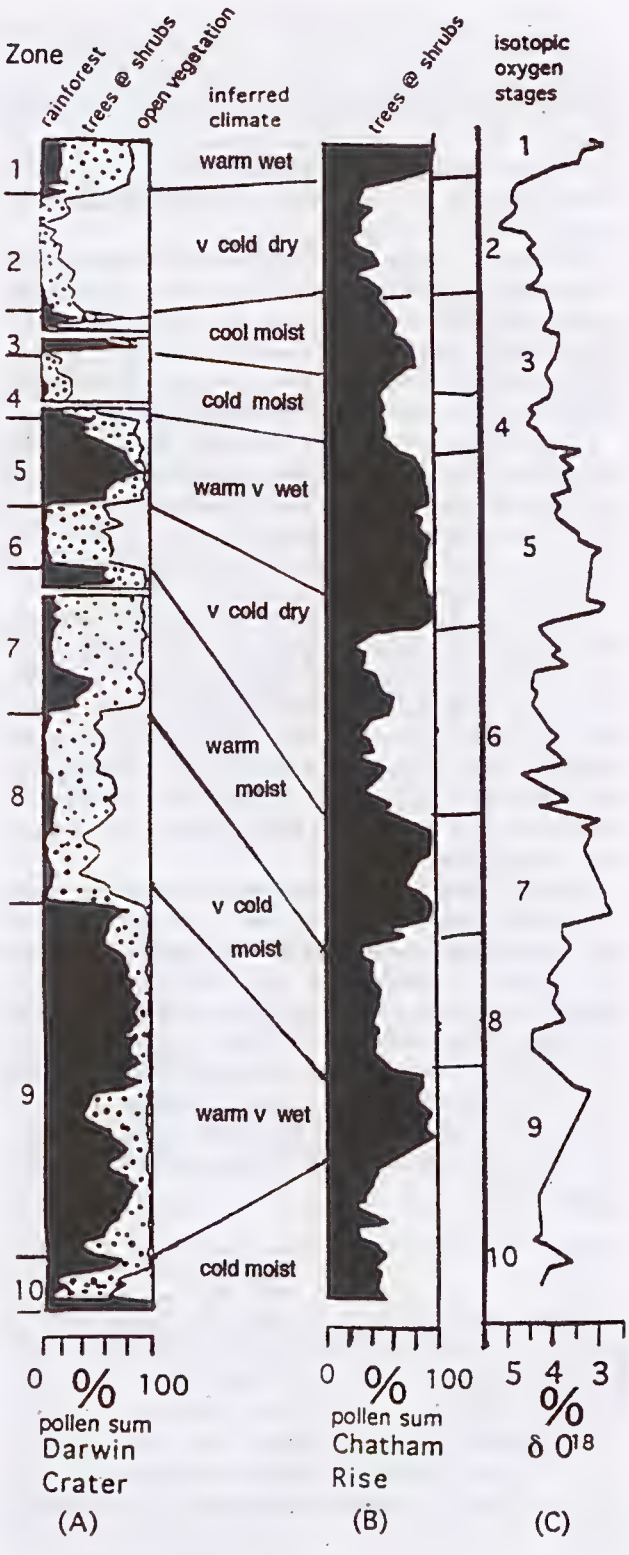


FIG. 4 — Summarised pollen sum diagrams of cores from (A) the Darwin Crater, western Tasmania (Colhoun & van de Geer 1988, 1998); (B) the ocean floor on the Chatham Rise, east of the South Island of New Zealand (Heusser & van de Geer 1994), and the zones of palaeoclimate and vegetation inferred in both diagrams (A) and (B) aligned with (C) the stages of the isotopic oxygen deficiency derived from the Chatham Rise core (Nelson et al. *1986).*

Chatham Rise core (B) and the $\delta^{18}O$ data (C) are indicated in figure 4 by lines between the columns. In this interpretation, the stages in the upper 20 m section of the Darwin Crater core and in the upper 40 m section of the Chatham Rise core encompass approximately the same span of palaeoclimate (~350 k yrs) or four glacial–interglacial cycles, ignoring the intermediate climates expressed by stages 3 and 4.

Colhoun & van de Geer suggested in a recent paper (1998) that stage 6 of the Chatham Rise core might correspond to the combined stages 6, 7 and 8 of the earlier interpretation. By ignoring the previous interglacial stage 7, this would shorten the coverage of the upper 20 m section of the Darwin Crater core to three glacial cycles.

There appears to be an appreciable increase in the percentage of open vegetation in both the cold, dry and the warm, wet climates during the Last Glacial cycle as compared with previous cycles in the Darwin Crater core. This shift in the proportion of open vegetation during the Last Glacial Cycle is not apparent in the Chatham Rise data.

The above observation can be analysed in detail by returning to the earlier interpretation of the data, where stages correspond to the $\delta^{18}O$ stages illustrated in figure 4C (Colhoun & van de Geer 1988, Colhoun 1989). This is shown in figure 5A for the Chatham Rise core and figure 5B for the Darwin Crater core, where the mean percentages of open vegetation in the stages corresponding to the $\delta^{18}O$ stages (Nelson *et al.* 1986) are plotted for the cold, dry and warm, wet climates.

In figure 4 and the following figures 5 and 6, the mean percentage of open vegetation in each 100 mm depth of the Darwin Crater core has been determined for each stage. The means are plotted at the midpoints of each stage. It should be mentioned that a number of hiatuses occur in the upper portion of the Darwin Crater core, due to gravel deposits. These are indicated in figure 4A by gaps. On the basis of core depth, the pollen record is missing in 58% of stage 3, 27% of stage 4 and 37% of stage 7. These hiatuses, especially those in stages 3 and 4, weaken inferences drawn from the data.

In the Chatham Rise data (fig. 5A) there is no apparent rise in the levels of open vegetation in stages 1, 3 and 4. The intermediate nature of the climate of stage 3 is evident. There is a small significant rise in the stage 2 glacial climate. In contrast, in the Darwin Crater data (fig. 5B), the level of open vegetation is effectively double that of the earlier stages. While the increase in stage 3 could be ascribed to the intermediacy of the climate in this stage, as is evident in the Chatham Rise data, the increased levels in the other stages of the last glacial cycle in the Darwin Crater data appear to have no explanation in terms of climate.

The above observations are substantiated by statistical tests on the differences between the mean percentages of open vegetation in sequential groups of stages up the Darwin Crater core within the separate cold, dry and warm, wet climates. These are shown in table 2A where the percentage of open vegetation for each 100 mm of the core has been averaged over each stage or group of stages after arcsine transformation. Within each climatic division, the sequential grouping of stages starting at the lower end of the core is shown in the first column, with the corresponding difference in mean in the second column. The value of the t-test function for this difference is shown in the fourth column. Apart from insignificant differences in the early stages of the cold, dry climates, other differences can be assumed to be real. The scale in the t-values indicates that the observed increase in open vegetation in stage 4 and later stages is real, with probability values several orders of magnitude lower than differences between earlier stages.

As additional support for increased levels of open vegetation during the last glacial cycle in the Darwin Crater data, it should be mentioned that a regression analysis of the percentage of open vegetation on core depth over the cold, dry climates of stages 2 and 4 shows significant relationships. The regression of the percentage of pollen from open vegetation taxa in each 100 mm sample on the position of the sample up the core in stage 4 shows an increase of 1.9% per sample with $r^2 = 0.59$, $P < 0.05$, while in stage two the increase is 1.2% per sample with $r^2 = 0.76$, $P < 0.001$. There are no significant trends in the earlier stages.

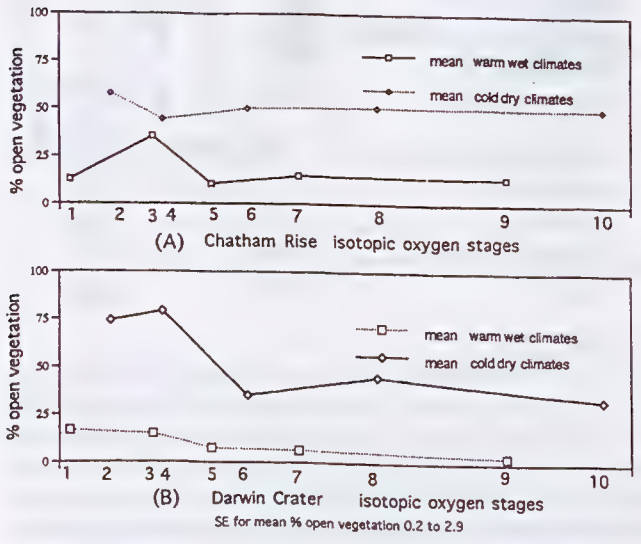

% open vegetation
mean warm wet climates
mean cold dry climates
(A) Chatham Rise isotopic oxygen stages
% open vegetation
mean warm wet climates
mean cold dry climates
(B) Darwin Crater isotopic oxygen stages
SE for mean % open vegetation 0.2 to 2.9

FIG. 5 — The mean percentage of open vegetation in stages of the isotopic oxygen deficit for cold, dry and warm, wet climates inferred from the pollen sums of (A) the Chatham Rise core and (B) the Darwin Crater core.

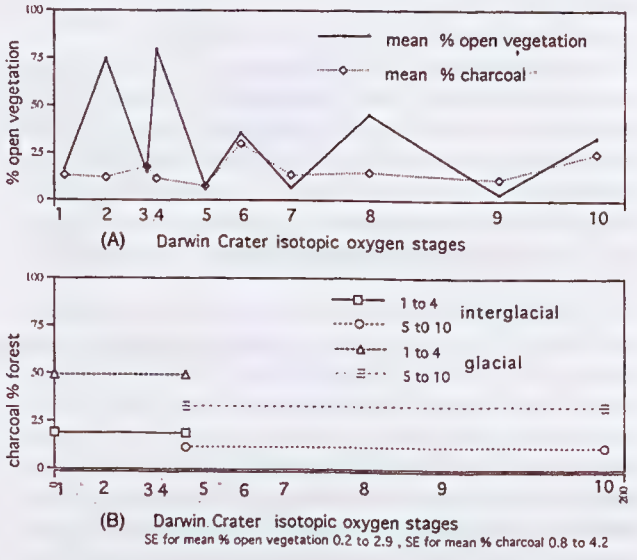

% open vegetation
mean % open vegetation
mean % charcoal
(A) Darwin Crater isotopic oxygen stages
charcoal % forest
1 to 4
5 to 10
interglacial
1 to 4
5 to 10
glacial
(B) Darwin Crater isotopic oxygen stages
SE for mean % open vegetation 0.2 to 2.9 , SE for mean % charcoal 0.8 to 4.2

FIG. 6 — (A) The mean percentage of open vegetation and the relative level of charcoal grains >20 μ in the isotopic oxygen stages of the Darwin Crater core. (B) The mean level of charcoal as a percentage of forest vegetation in the cold, dry and warm, wet climates of stages 1, 2, 3 and 4, compared with those climates in stages 5 to 10 of the Darwin Crater core.

TABLE 2
Summary of significance tests

(A) Differences between means of open vegetation in oxygen-isotope stages and groups of stages of the Darwin Crater core (Colhoun 1989); see figure 5B.

Cold, dry climates					*Warm, wet climates*				
Sequential grouping of stages	Difference in means	n	t	P	Sequential grouping of stages	Difference in means	n	t	P
8–10	7	32	2.1	0.05	7–9	4.4	84	6.3	<0.001
6–(8 & 10)	4.5	42	2.4	0.05	5–(7 & 9)	4.3	97	4.2	<0.001
4–(6, 8 & 10)	23.4	50	10.9	<0.001	3–(5, 7 & 9)	10.7	101	5.6	<0.001
2–(4, 6, 8 & 10)	16.3	63	5.5	<0.001	1–(3, 5, 7 & 9)	11.7	107	6.7	<0.001
(2 & 4)–(6, 8 & 10)	21.2	63	14	<0.001	(1 & 3)–(5, 7 & 9)	11.6	107	9.2	<0.001

(B) Difference in mean percentage of charcoal levels between oxygen-isotope stages 1–4 and stages 5–10 of the Darwin Crater core (Colhoun 1989; see figure 6A.

Grouping of stages	Difference in means	n	t	P
(1, 2, 3 & 4)–(5, 6, 7, 8, 9 & 10)	2.83	182	1.11	0.25

(C) Differences in mean percentage of charcoal levels relative to forest levels between groups of isotopic oxygen stages during the Last Glaciation compared with previous cycles; see figure 6B.

Cold, dry climates					*Warm, wet climates*				
Grouping of stages	Difference in means	n	t	P	Grouping of stages	Difference in means	n	t	P
(2 & 4)–(6, 8 & 10)	7.58	69	3.63	<0.001	(1 & 3)–(5, 7 & 9)	4.33	111	2.01	~0.04

It should be emphasised that the hiatuses in the pollen record, which are due to gravel deposition in stages 3 and 4, weaken the strength of the above analysis and the value of the inferences flowing from it. It is possible that another coring of the crater might provide an uninterrupted pollen record.

Charcoal levels

Colhoun & van de Geer (1988, 1998) scored the number of grains of charcoal >20 μ in size in each of the 100 mm sample length of the Darwin Crater core. The mean for all samples in each of the $\delta^{18}0$ stages has been determined. This provides a comparative measure of wildfire incidence between stages on a nominal scale.

The mean relative charcoal levels for stages in the Darwin Crater core are shown in figure 6A, plotted on the same diagram as the percentage of open vegetation. No relationship between the scales for charcoal and open vegetation is inferred.

There is a trend in figure 6A for higher charcoal levels in glacial climates, levels in $\delta^{18}0$ stages 6 and 10 being particularly high. Conversely, there is a trend for lower levels in the warm, wet climates. This indicates that conditions drier than at present, as have been proposed for the Last Glaciation (Markgraf *et al.* 1986), have been duplicated in past glacial episodes. The general level of charcoal throughout the core certainly shows that wildfire has always been a part of Tasmanian environment during the Late Pleistocene.

There does not appear to be any increased level of charcoal accompanying the increased levels of open vegetation during the Last Glacial cycle. This observation is verified statistically in table 2B, showing the t-test for the difference in the mean level of charcoal over stages 1–4 and the mean of earlier stages 5–10. No significant difference is indicated. However, the more or less average levels of charcoal in stages 1–4 cannot be construed to mean there was no increase in the level of fire during the period, since the amount of woody vegetation necessary to produce charcoal in the surrounding catchment was much reduced during

the Last Glacial Cycle (38.5%) compared with 78.8% earlier.

This is demonstrated in figure 6B, where the mean level of charcoal relative to woody vegetation is plotted for the cold, dry and the warm, wet climates during the Last Glacial Cycle and compared with earlier cycles. Table 2C shows, by t-tests for the differences in means, that the increase in charcoal levels in the cold stages of the Last Glacial Cycle compared with previous cycles is highly significant. The corresponding increase in the warm, wet climates is also significant at P = 0.04.

DISCUSSION

As might be expected, the correspondence between the records of palaeovegetation from the Darwin Crater core (42°19'S) and from the Chatham Rise core (45°31'S) is very close (fig. 4A, B). Each glacial episode produces a decrease in woody vegetation, especially rainforest species, and an increase in herbaceous vegetation and grassland to about 40–50% of the total. The shorter interglacial climate periods are marked by a preponderance of forest, with the open vegetation reduced to between 5 and 15% of the total. As figure 5A, B indicates, these proportionate levels of open vegetation relative to closed forest remain nearly constant in both warm, wet and cold, dry climates, except in the last glacial cycle of the Darwin Crater core.

Both the New Zealand and Tasmanian data demonstrate greater variation in the responses of the vegetation to the climates of both cold, dry and warm, wet periods during the last cycle as compared with the previous three cycles. A considerable part of this can be attributed to the lower amplitude and shorter periods of the isotope stages 3 and 4. This probably accounts for the intermediate responses of the vegetation during zones 3 and 4 of the New Zealand data in figure 5A compared with the longer and more extreme climates of the previous three cycles.

The data for zone 4 of the Darwin Crater core show a major change in the reverse direction to that of zone 4 of the New Zealand data. A massive decrease in the amount of the forest vegetation is indicated. This increase in the amount of open vegetation is maintained in the succeeding zones of 3, 2, and 1. This parallel shift in the mean values of open vegetation in both the cold, dry and warm, wet climates for the last cycle of the Darwin Crater is not present in the New Zealand data.

During the Last Glacial cycle the record of palaeovegetation in the Darwin Crater core shows a two-fold increase in the proportion of open vegetation in both the cold, dry and the warm, wet climates in comparison with levels in previous cycles (fig. 5B, table 2A). The proportion of eucalypts relative to rainforest increases and the proportion of rainforest decreases (fig. 4A). The count of carbon particles relative to the amount of woody vegetation increases (fig. 6B, table 2C). The absence of a similar response in New Zealand vegetation infers that the changed responses of the vegetation in Tasmania are the result of increased levels of fire due to human activity.

The simultaneous increase in non-forest vegetation over the Last Glacial cycle in two quite different climates in Tasmania is suggestive of a cause other than climate and is entirely consistent with the response in vegetation which is expected to accompany the presence of Aborigines (Jackson 1968, Bowman & Jackson 1981, Jackson & Bowman 1982). As detailed in the introduction, the Aborigines had well-established practices of fire management. They carried fire when on the move and used fire as a tool in hunting, in communication, in warfare and, above all, in controlling game populations by patch-burning vegetation to provide "green-pick" grazing conditions. These activities would produce marked increases in the openness of the vegetation by restricting closed forests and engendering pyrogenic fire tolerant vegetation with fine fuels and vegetative reproduction.

CONCLUSION – A SUGGESTED EARLIER OCCUPATION OF TASMANIA BY THE ABORIGINES

The Darwin Crater core demonstrates a two-fold increase in the amount of open, non-forest vegetation in the Last Glacial cycle, as compared with levels in the previous three glacial cycles. The divergence from previous patterns commences early in $\delta^{18}0$ stage 4. The climate in $\delta^{18}0$ stage 4 produced near glacial conditions in western Tasmania. Fitzsimons & Colhoun (1991) and Colhoun & Fitzsimons (1990) reported evidence of an ice advance, the Chamouni Formation, in the upper King River valley, with till and outwash gravels, laminated silts and plant debris. An age of 61–73 k yrs is suggested for this formation. It is, therefore, understandable that the amount of open vegetation displayed in the Darwin Crater core in this stage would be high. However, the Chatham Rise core shows no parallel increase in open vegetation during $\delta^{18}0$ stage 4 as compared with previous cycles.

This divergence from previous patterns in the Darwin Crater core continues during the whole of $\delta^{18}0$ stage 4 and, thereafter, during $\delta^{18}0$ stages 3, 2 and the Holocene.
We know from the anthropological evidence (Cosgrove 1995, Cosgrove *et al.* 1990) that the Aborigines occupied limestone valleys throughout western and southern Tasmania during the later periods of $\delta^{18}0$ stage 3 with ^{14}C dating to 34 ka (Cosgrove 1995: fig. 16).

The above palaeovegetation evidence suggests a considerably earlier date for the occupation of Tasmania by the Aborigines. This infers that the ^{14}C dates obtained for the cave and rock-shelter sites are considerable underestimates. Such underestimation by the ^{14}C methodology for palaeomaterial > 30 k yrs in western Tasmania is usual (Colhoun 1986) and is well recognised by Tasmanian palaeoworkers. The groundwater in western and southern Tasmania carries large amounts of humic and humus acids from the peaty surface soil. Such a supply of modern carbon, gradually exchanging with older carbon in buried material, causes these underestimates. It seems likely that Aboriginal occupation of Tasmania may have ocurred as early as 70 000 BP. This conclusion is supported by a variety of botanical evidence.

REFERENCES

BISHOFF, J., 1832: Report to V.D.L. Co. 1828. *HISTORY OF AND ACCOUNT OF THE VAN DIEMEN'S LAND CO.* Richardson, London: 118.

BOERNER, R.E.J., 1982: Fire and nutrient cycling in temperate ecosystems. *Bio Sci.* 32: 187–192.

BOWDEN, A.R., 1983: Relict terrestrial dunes: legacies of a former climate in coastal northeastern Tasmania. *Z. Geomorphol. N.F.* 45: 153–174.

BOWMAN, D.M.J.S. & JACKSON, W.D., 1981: Vegetation succession in southwest Tasmania. *Search* 12: 358–362.

BOWMAN, D.M.J.S. & BROWN, M.J., 1986: Bushfires in Tasmania, a botanical approach to anthropological questions. *Archeol. Oceania* 21: 166–171.

BOWMAN, D.M.J.S., MACLEAN, A.R. & CROWDEN, R.K., 1986: Vegetation–soil relations in the lowlands of south-west Tasmania. *Aust. J. Ecol.* 11: 141–153.

BROWN, M.J. & BAYLY-STARK, H.J., 1979: Vegetation of Maria Island. *Wildl. Div. Tech. Rep.* 79/1. NPWS, Hobart.

BROWN, M.J. & PODGER, F., 1982a: On the apparent anomaly between observed and predicted percentages of vegetation types in South-West Tasmania. *Aust. J. Ecol.* 7: 3–12.

BROWN, M.J. & PODGER, F., 1982b: Floristics and fire regimes of a vegetation sequence from sedgeland-heath to rainforest at Bathurst Harbour, Tasmania. *Aust. J. Bot.* 30: 659–676.

BROWN, M.J. & PODGER, F.D. 1982c: Rainforest-sedgeland transitions. *In* Felton, K. (Ed.): *TASMANIAN RAINFORESTS-RECENT RESEARCH RESULTS.* Forest Ecology Research Fund, Hobart: 47–53.

CHENEY, A.P., 1981: Fire behaviour. *In* Gill, A.B., Groves, R.H. & Nobel, I.R. (Eds): *FIRE AND THE AUSTRALIAN BIOTA.* Australian Academy of Science, Canberra: 151–176.

COLHOUN, E.A., 1977: A sequence of Late Quaternary deposits at Pipe Clay Lagoon southeastern Tasmania. *Pap. Proc. R. Soc. Tasm.* 111: 1–12.

COLHOUN, E.A., 1986: Field problems of radiocarbon dating in Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 1–6.

COLHOUN, E.A., 1989: The Quaternary. *In* Burrett, C.F. & Martin, E.L. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ.*: 410–418.

COLHOUN, E.A. & FITZSIMONS, S.J., 1990: Late Cainozoic glaciation in western Tasmania, Australia. *Quat. Sci. Rev.* 9: 199–216.

COLHOUN, E.A. & VAN DE GEER, G., 1988: Darwin Crater the King and Linda valleys. *In* Colhoun, E.A. (Ed.): *CAINOZOIC VEGETATION OF TASMANIA. Univ. Newcastle Spec. Pap.* Dep. Geogr., Univ. Newcastle: 30–71.

COLHOUN, E.A. & VAN DE GEER, G., 1998: Pollen analysis of 0–20 m at Darwin Crater western Tasmania, Australia. *In* Horie, S. (Ed.): *International project on palaeolimnology and Late Cainozoic climate. IPPCE* 11: 68–89.

COSGROVE, R., 1995: Late Pleistocene behavioural variation and time trends: the case from Tasmania. *Archaeol. Oceania* 30: 83-104.

COSGROVE, R., ALLEN, J. & MARSHALL, B., 1990: Palaeoecology and Pleistocene human occupation in south central Tasmania. *Antiquity* 64: 59–78.

DUNCAN, F., 1990: Eucalypts in Tasmania's changing landscape. *Tasforests* 2: 151–166.

ELLIS, R.C., 1986: The relationship between sub-alpine grassland and forest communities in northern Tasmania. *In* Barlow, B.A. (Ed.): *FLORA AND FAUNA OF ALPINE AUSTRALIA AGES AND ORIGINS.* CSIRO, Melbourne: 243–248.

FENSHAM, R.J., 1989: The pre-European vegetation of the Midlands Tasmania: a floristic and historical analysis of vegetation pattern. *J. Biogeogr.* 16: 29–45.

FITZSIMONS, S.J. & COLHOUN E.A., 1991: Pleistocene glaciation of the King Valley western Tasmania, Australia. *Quat. Res.* 36: 135–156.

FORD, R.J., 1972. A possible impact crater associated with Darwin Glass. *Earth Planet. Sci. Lett.* 16: 228–230.

FUDALI, J. & FORD, R.J., 1979. Darwin Glass and Darwin Crater — a progress report. *Meteoritics* 14: 283–296.

GENTNER, W., KIRSTEN, T., STORZER, D. & WAGNER, G.A., 1973: K-Ar and fission track dating of Darwin Crater glass. *Earth Planet. Sci. Lett.* 20: 203–210.

GILBERT, J.M., 1959. Forest succession in the Florentine Valley Tasmania. *Pap. Proc. R. Soc. Tasm.* 93: 129–151.

HARRIS, S. & KIRKPATRICK, J.B., 1991: The distributions, dynamics and ecological differentiation of *Callitris* species in Tasmania. *Aust. J. Bot.* 39: 187–202.

HARWOOD, C.E., 1972. Nutrient studies in south-west Tasmanian vegetation. Unpubl. BSc Hons thesis, Dep. Botany, Univ. Tasm., Hobart.

HENDERSON, W. & WILKINS, C.W., 1975: The interaction of bushfires and vegetation. *Search* 16: 130–133.

HEUSSER, L.E. & VAN DE GEER, G., 1994: Direct correlation of terrestrial and marine palaeoclimatic records from four glacial–interglacial cycles — DSDP Site 594. Southwest Pacific. *Quat. Sci. Rev.* 13: 273–282.

HOLLAND, B.G. & STEYN, D. G., 1975: Vegetation responses to latitudinal variations in slope angle and aspect. *J. Biogeogr.* 2: 179–183.

INGLES, A., 1985: Fire. *Environmental Impact statement into the continuation of woodchip exports from Tasmania after 1990. Working paper No. 5.* Government Printer, Hobart.

JACKSON, W.D., 1965: Vegetation. *In* Davies, J.L. (Ed.): *ATLAS OF TASMANIA.* Lands and Surveys, Hobart: 30–35.

JACKSON, W.D., 1968: Fire, Air, Water and Earth — an elemental ecology of Tasmania. *Proc. Ecol. Soc. Aust.* 3: 9–16.

JACKSON, W.D., 1977: Nutrient cycling in Tasmanian oligotrophic environments. *PROCEEDINGS OF THE SYMPOSIUM ON NUTRIENT CYCLING AND INDIGENOUS FOREST ECOSYSTEMS.* CSIRO, Division of Land Resource Management, Perth, WA: 122–123.

JACKSON, W.D., 1981a: The Tasmanian environment. *In* Jackson, W.D. (Ed.): *VEGETATION OF TASMANIA. XIII International Botanical Congress, Sydney: Field Trip 28.* Australian Academy of Science, Canberra: 1–10.

JACKSON, W.D., 1981b: Vegetation and fire patterned vegetation. *In* Jackson, W.D. (Ed.): *VEGETATION OF TASMANIA. XIII International Botanical Congress, Sydney: Field Trip 28.* Australian Academy of Science, Canberra: 11-35.

JACKSON, W.D., 1981c: Wet Sclerophyll. *In* Jackson, W.D. (Ed.): *VEGETATION OF TASMANIA. XIII International Botanical Congress, Sydney: Field Trip 28.* Australian Academy of Science, Canberra: 68–72.

JACKSON, W.D., 1983: Tasmanian rainforest ecology. *In* Blakers, E.R. & Robertson, P. (Eds): *TASMANIAN'S RAINFORESTS, WHAT FUTURE?* Australian Conservation Foundation: 9–39.

JACKSON, W.D., 1999a: Vegetation types. *In* Reid, J.B., Hill, R.S., Brown, M.J. & Hovenden, M.J. (Eds): *VEGETATION OF TASMANIA.* Australian Biological Resources Study, Canberra: 1–10.

JACKSON, W.D., 1999b: The Tasmanian environment. *In* Reid, J.B., Hill, R.S., Brown, M.J. & Hovenden, M.J. (Eds): *VEGETATION OF TASMANIA.* Australian Biological Resources Study, Canberra: 11–34.

JACKSON, W.D., 1999c: Palaeohistory of vegetation change – the last 2 million years. *In* Reid, J.B., Hill, R.S., Brown, M.J. & Hovenden, M.J. (Eds): *VEGETATION OF*

TASMANIA. Australian Biological Resources Study, Canberra: 64–89.

JACKSON, W.D. & BOWMAN, D.M.J.S., 1982: Slash burning in Tasmanian dry eucalypt forests, Comment. *Aust. For.* 1: 63–67.

JACKSON, W.D. & BROWN, M.J., 1999: Pattern and process in the vegetation. . *In* Reid, J.B., Hill, R.S., Brown, M.J. & Hovenden, M.J., (Eds) *VEGETATION OF TASMANIA.* Australian Biological Resources Study, Canberra: 364–387.

JARMAN, S.J. & BROWN, M.J., 1983: A definition of cool temperate rainforest in Tasmania. *Search* 14: 81–87.

KIERNAN, K., 1989: Muliple glaciation of the upper Franklin Valley, Western Tasmania wilderness world heritage area. *Aust. Geogr. Stud.* 27: 208–235.

KIRKPATRICK, J.B., 1986: Tasmania alpine biogeography and ecology and interpretations of the past. *In* Barlow, B.A. (Ed.): *FLORA AND FAUNA OF ALPINE AUSTRALIA AGES AND ORIGINS.* CSIRO, Melbourne: 229–242.

KIRKPATRICK, J.B. & DICKINSON, K.J.M., 1984: *VEGETATION MAP OF TASMANIA 1:500,000.* Forestry Commission, Hobart.

KIRKPATRICK, J.B., BARKER, P., BROWN, M.J., HARRIS, S. & MACKIE, R., 1995: The reservation status of Tasmanian vascular plant communities. *Wildl. Sci. Rep.* 4. N.P.W.S., Hobart.

LA BILLARDIERE, J.J., 1800: *AN ACCOUNT OF A VOYAGE IN SEARCH OF LA PERUSE IN THE YEARS 1791, 1792, 1793. Vol. II.* London: 26–63.

LING ROTH, H., 1899: *THE ABORIGINES OF TASMANIA.* 2nd edn. King & Sons, Halifax, England.

MACLEAN, A.R., 1979: Mineral nutrients in soils and vegetation of sedgeland and heathland communities in south-west Tasmania. Unpubl. BSc Hons. thesis, Dep. Bot., Univ. Tasm., Hobart.

MACPHAIL, M.K., 1979: Vegetation and climates in southern Tasmania since the last glaciation. *Quat. Res.* 11: 306–341.

MACPHAIL, M.K., 1980: Regeneration processes in Tasmanian forests. *Search* 11: 184–190.

MARKGRAF, V., BRADBURY, J.P. & BUSBY, J.R., 1986: Palaeoclimate in southwestern Tasmania during the last 13,000 years. *Palaios* 1: 368–380.

MARSDEN-SMEDLEY, J.B., 1998a: Fire and fuel in Tasmanian buttongrass moorlands: regimes, characteristics, behaviour and management. Unpubl. PhD thesis, Sch. Geogr. Environ. Stud., Univ. Tasm., Hobart.

MARSDEN-SMEDLEY, J.B., 1998b: Changes in southwest Tasmania fire regimes since the early 1800s. *Pap. Proc. R. Soc. Tasm.* 132: 15–29.

MILLIGAN, J., 1858: Vocabulary of the dialects of some of the aboriginal tribes of Tasmania. *Pap. Proc. R. Soc. Tasm.* 3: 239–274.

MOUNT, A.B., 1979: Natural regeneration processes in Tasmanian forests. *Search* 10: 180–186.

MOUNT, A.B., 1982: Fire cycles in south-west Tasmania. *Search* 13: 174–175.

NELSON, C.S., HENDY, C.H., CUTHBERTSON, A.M. & JARRETT, G.R., 1986: Late Quaternary carbonate and isotope stratigraphy, subantarctic site 594, southwest Pacific. *In* Kennett, J.P. & van der Borch, C.C. (Eds): *INITIAL REPORTS OF THE DEEP SEA DRILLING PROJECT.* U.S. Gov. Pr. Office Washington D.C.: 1425–1436.

NICOLLS, K.D., 1958: Aeolian deposits in river valleys in Tasmania. *Aust. J. Sci.* 21: 50–51.

NOBLE, I.R. & SLATYER, R.O., 1981: Concepts and models of succession in vascular plant communities subject to recurrent fire. *In* Gill, A.M., Groves, R.H. & Noble, I.R. (Eds): *FIRE AND AUSTRALIAN BIOTA.* Australian Academy of Science, Canberra: 311–335.

NUNEZ, M., 1978: The radiation index of dryness in Tasmania. *Aust. Geogr. Stud.* 16: 126–135.

PLOMLEY, N.J.B., 1966: *FRIENDLY MISSION, THE TASMANIAN JOURNALS AND PAPERS OF GEORGE AUGUSTUS ROBINSON 1829–1834.* Tasmanian Historical Research Association, Halstead, Kingsgrove, NSW.

PODGER, F.D., BIRD, T. & BROWN, M.J., 1989: Human activity, fire and change in the forest at Hogsback Plain, southern Tasmania. *In* Frawley, K.J. & Semple, N. (Eds): *AUSTRALIA'S EVER CHANGING FORESTS.* Australian Defence Force Academy, ACT.

READ, J., 1985: Photosynthetic and growth responses to different light regimes of the major canopy species of Tasmanian cool temperate rainforest. *Aust. J. Ecol.* 10: 327–334.

REID, J.B. & POTTS, B.M. 1999: Eucalypt biology. *In* Reid, J.B., Hill, R.S., Brown, M.J. & Hovenden, M.J. (Eds): *VEGETATION OF TASMANIA.* Australian Biological Resources Study, Canberra: 203–228.

REID, J.B., HILL, R.S., BROWN, M.J. & HOVENDEN, M.J. (Eds), 1999: *THE VEGETATION OF TASMANIA.* Australian Biological Resources Study, Canberra: 440 pp.

R.F.A., 1996: *TASMANIAN–COMMONWEALTH REGIONAL FOREST AGREEMENT. Environment and Heritage Report, Vol. 1. Background Report Part C.* Tasmanian Public Land Use Commission: 210 pp.

SCOTT, P., 1956: Variability of annual rainfall in Tasmania. *Pap. Proc. R. Soc. Tasm.* 90: 499–557.

SIGLEO, W.R. & COULHOUN, E.A., 1981: A short pollen diagram from Crown Lagoon in the Midlands of Tasmania *Pap. Proc. R. Soc. Tasm.* 115: 181–188.

SIGLEO, W.R. & COLHOUN, E.A., 1982: Terrestrial dunes, man and the Late Quaternary environment in southern Tasmania. *Paleogeog. Paleoclim. Paleoecol.* 39: 87–121.

WITHERS, J. & ASHTON, D.H., 1977: Studies on the status of unburnt *Eucalyptus* Woodland at Ocean Grove, Victoria. I. The structure and regeneration. *Aust. J. Bot.* 25: 623–637.

(accepted 25 January 1999)

THE EFFECTS OF FIRE ON BURROW-NESTING SEABIRDS PARTICULARLY SHORT-TAILED SHEARWATERS (*PUFFINUS TENUIROSTRIS*) AND THEIR HABITAT IN TASMANIA

by Nigel Brothers and Stephen Harris

(with three text-figures, four plates and an appendix)

BROTHERS, N. & HARRIS, S., 1999 (31:x): The effects of fire on burrow-nesting seabirds particularly short-tailed shearwaters *(Puffinus tenuirostris)* and their habitat in Tasmania. *Pap. Proc. R. Soc. Tasm.* 133(1): 15–22. ISSN 0080–4703. Parks and Wildlife Service, Department of Primary Industries, Water and Environment, GPO Box 44A, Hobart, Tasmania, Australia 7001.

The synchronised breeding habit of many seabird species makes them particularly vulnerable to fires in the nesting area. Post-fire recolonisation and soil formation were studied on Albatross Island, and observations from island rookeries of shearwaters, fairy prions and fairy penguins in eastern Bass Strait and elsewhere were used with a view to understanding the long-term impact of fires on seabird colonies in Tasmania.

Key Words: island vegetation, flora, Tasmania, fire, coast, rookeries, seabirds, soil depth, *Puffinus tenuirostris*, Bass Strait, habitat monitoring.

INTRODUCTION

Large populations of seabirds breed on islands around Tasmania and it is on these islands that wildfires frequently occur, mostly through vandalism, sometimes by accident. Deliberate burning by land managers also occurs.

It is difficult to understand fully the long-term effects of a fire on seabirds such as short-tailed shearwaters, planned destructive experiments in bird rookeries being unacceptable. The best chance of obtaining empirical data on fire effects is to establish plots in selected rookeries which can then be sites for data collection following any chance disturbance such as fire. The timing of the fire in relation to the stage of seabird breeding cycles will have different impacts on populations.

Several studies have examined the effects of soil nutrients, soil moisture and seabird activity in Australian rookeries (Gillham 1960a,b, Brown *et al.* 1993, Walsh *et al.* 1997). Documentation of the effects of fire on soils and vegetation in seabird rookeries is rare.

This study was made in the interests of understanding and, it is to be hoped, to reducing the long-term impact of fire on seabird colonies

MATERIALS AND METHODS

Site Descriptions

Albatross Island study site

Pre-fire vegetation

Albatross Island, in southwestern Bass Strait (fig. 1) has an area of 100 ha. Soils with 90% humus content are intermittently scattered between bare rock outcrops, in many places being only several centimetres deep but up to 0.5 m in gully areas. Vegetation is dominated by succulents, particularly *Disphyma crassifolium* and *Senecio lautus*. *Tetragonia implexicoma* occurs sporadically over the island, especially amidst the protection of boulders. It was not a component of the pre-fire vegetation at the study site. *Poa poiformis* is dominant in many localities, particularly where soils are deep, and it is in such circumstances that burrow-nesting seabirds are found in greatest abundance. Short-tailed shearwaters, *Puffinus tenuirostris*, are most abundant in this habitat, with small numbers of little penguin, *Eudyptes minor*, scattered throughout. Figure 2 indicates the location of colony A and colony B with respect to the effects of fire. Elsewhere, outside colonies A and B, fairy prions, *Pachyptila turtur*, are abundant, nesting in rock crevices and in burrows, as they are considerably less limited by the shallow soil depth here than the larger short-tailed shearwaters. Short-tailed shearwaters and little penguins do, however, nest outside colonies A and B but mostly in sparsely scattered burrows. There is a total of approximately 2000 short-tailed shearwater, 350 little penguin and 20 000 fairy prion pairs nesting on the island.

Figure 2 also shows the location of shy albatross, *Diomedea cauta*, colonies. Albatrosses have reduced the whole of their colony to bare rocks as vegetation and soil are used in nest-mound construction. This is most relevant to the extent of soil and vegetation elsewhere on the island, as Robinson (in Plomley 1966) originally observed the island as being "covered in birds" and Brothers (pers. obs.) plotted the former extent of the albatross colony as indicated by guano-encrusted rock, which encompasses colonies A and B. From this and the nesting habits of albatrosses as described, it is reasonable to assume that the vegetation and soils and, therefore, burrow-nesting seabirds in colonies A and B are of recent origin, approximately 100 years.

There are no introduced vertebrates on Albatross Island.

Pre-fire burrow densities

Before the 1982 fire (see below), short-tailed shearwater burrow density in colony A was 0.57/m^2 (ten 2.5 m radius circular plots range 7–17, mean 11.1). The total number of burrows in the 1250 m^2 of colony was about 700. Colony B pre-fire burrow density was 0.59/m^2 (ten 2.5 m radius circular plots, range 6–13, mean 11.5) or a total of about 350 burrows in 600 m^2, which is the extent of this colony. Some nest sites included in the above figures at both colonies were in the base of matted *Poa poiformis* tussocks, there being insufficient depth of soil for burrowing.

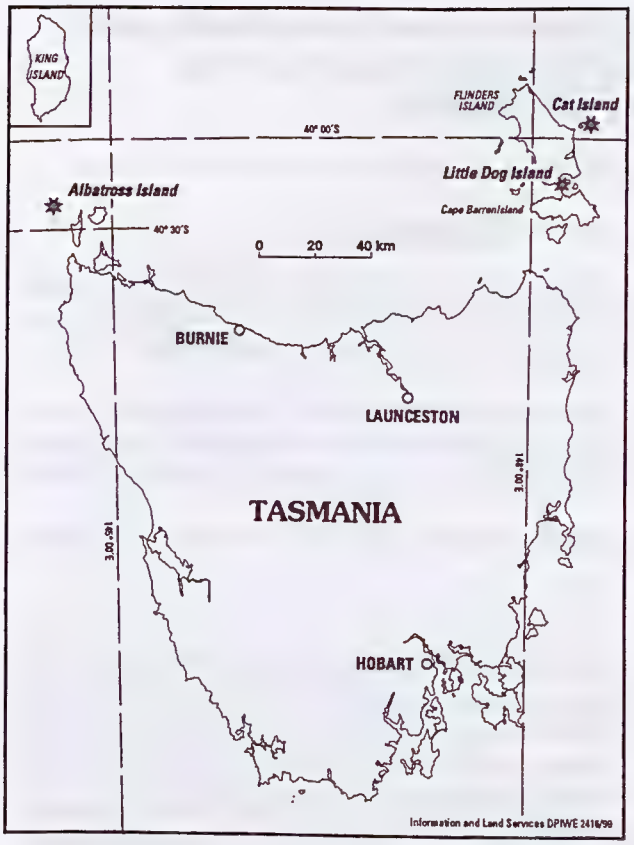


FIG. 1 — Locations of Albatross, Cat and Little Dog Islands.

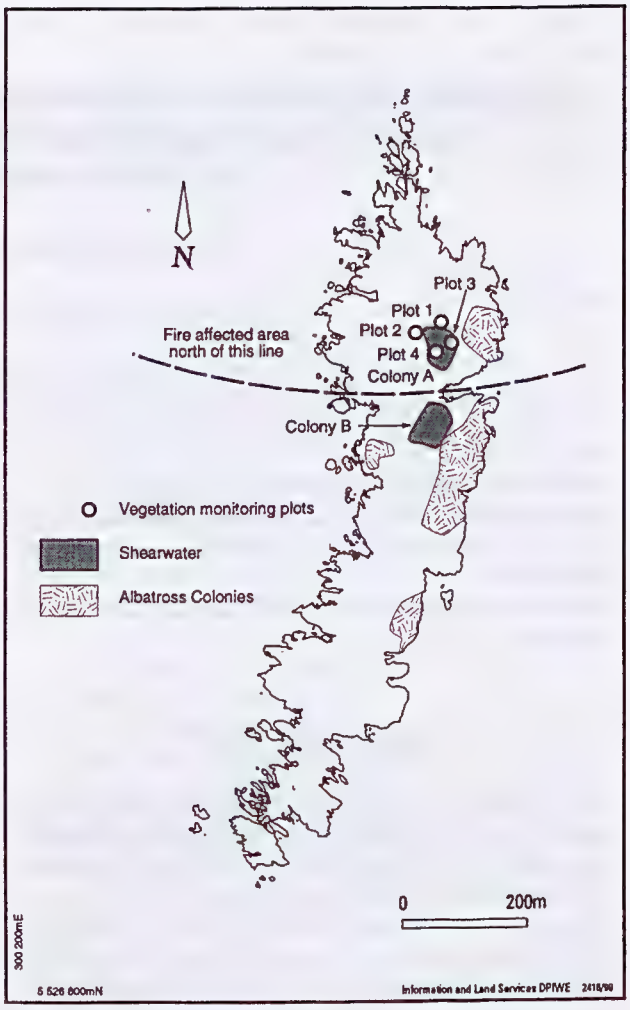


FIG. 2 — Albatross Island, showing locations of sampling plot sites, location of rookeries and extent of burnt area.

Fire description

An accidentally lit fire in February 1982 burnt 20 ha in the north of Albatross Island (fig. 2). The fire self-extinguished after several days, but not before all vegetation had been destroyed and soil reduced to scorched patches a few millimetres deep, surrounded by bare rock (pl. 1). A ravine intersecting the island prevented more extensive destruction. Figure 2 shows the extent of the fire, Colony A being totally destroyed, Colony B unaffected. Apart from the destruction of shearwater, prion and penguin habitat, a potential long-term effect of the fire, seabirds present in their colonies at the time of the fire were incinerated. Penguin burrows could have contained chicks and some adults at the time and up to 100 individuals may have died. Fairy prion chicks fledge by early February so, apart from small numbers of adult prions that occasionally stay ashore in burrows, thousands of this species escaped destruction by only a matter of weeks. For short-tailed shearwaters the timing of the fire was not so favourable, as chicks would have been about one month old. Apart from the 700 in Colony A, another 200 are estimated to have died in the areas burnt. An unknown number of juvenile birds that are very active at this time of the year selecting nesting sites and mates frequently stay ashore during day time, as does the occasional adult breeding bird attending its chick, and not all would have escaped the fire.

Other islands

Little Dog Island (66 ha) is situated in Franklin Sound in the Furneaux Group. It is dominated by *P. poiformis* tussock grassland. Cat Island (49 ha) is low and grassy and its vegetation is also dominated by *P. poiformis*. It is a part of the Babel Group off the east coast of Flinders Island. Brief descriptions of other island rookeries around Tasmania are given in Naarding (1981).

Sampling Methods

Albatross Island

Vegetation recovery

To measure the recovery of vegetation and shearwater breeding, the corners of four 5 m^2 plots were marked with PVC poles and assessed annually (in September) for changes in vegetation from 1982 (two measurement events) to 1990 and then again in 1998. The percentage cover of each plant species in each plot was assessed. Vegetation recovery Plot 2 was located away from shearwater habitation, Plot 1 was in peripheral shearwater colony habitat, whereas Plots 3 and 4 were in areas of highest pre-fire nesting density.

Soil depth

Soil depths were obtained by repeatedly positioning at random a steel spike throughout each area and measuring the length of the spike from ground surface to contact with rock.

PLATE 1
Colony A Albatross Island, destruction by fire March 1982.

PLATE 2
Colony A Albatross Island, vegetation recovery six years after the 1982 fire.

PLATE 3
Colony B Albatross Island, habitat destruction due to excessive shearwater activity.

PLATE 4
Shearwaters and Gannets killed by fire, Cat Island, 1984.

Nest densities

Nesting densities were calculated from the number of burrow entrances counted within circular plots (radius 2.5 m) randomly located through shearwater colonies. Searches of the plots were undertaken annually (in September, December and April) for shearwater occupancy and breeding success.

Other islands

Burrows were examined after fires on both Little Dog and Cat Islands in the Furneaux Group. Observational data were collected, enabling some comparisons between these islands and Albatross Island.

A published checklist (Naarding 1981) of shearwater colonies was used in assessing the number of rookeries which have been burned. The assessment was made from personal recollection, field notes and observations of physical evidence of fire.

RESULTS

Post-fire Vegetation Recovery

At all four sites, recolonisation to 100% cover of vegetation (fig.3) occurred by the sixth year, principally by *Disphyma crassifolium* and *Senecio lautus*. *D. crassifolium* is an excellent perennial ground-cover plant that would assist in soil stabilisation and provide shelter for other plant species that take longer to re-establish. This is apparently the case for *P. poiformis*, which is slower to re-establish but, having done so, is capable of displacing *D. crassifolium* and *S. lautus* (fig.3).

In the first two years following the fire, all plots had one or two very small patches of *Pelargonium australe* and *Crassula sieberiana* but these species subsequently disappeared, presumably due to encroachment of *D. crassifolium*. Elsewhere on the island, *C. sieberiana* is common but restricted to small patches in rock crevices and *P. australe* occurs as isolated scattered plants amongst *D. crassifolium*. Whilst *S. lautus* is even more adept at re-establishing than *D. crassifolium*, this species has a comparatively short spring growing season after which it dies back, again exposing soil to erosion. Colloquially known as "fire weed", this species flourishes after fire and also favours areas of high soil disturbance, for example, in and around shearwater colonies. Hence, in Plots 3 and 4 the re-emergence of this species coincides with renewed vigorous shearwater burrowing activity. It is anticipated that *S. lautus* will become co-dominant with *Poa poiformis* ultimately. Plot 2 was indistinguishable from unburnt, similar habitat on the island in its third year of regeneration with the relative abundance of *D. crassifolium* and *S. lautus* fluctuating annually. Vegetation recovery is portrayed in plate 2.

Post-fire Soil Regeneration

As previously stated, it is not known what proportion of shearwaters in Colony A, prior to the fire, were nesting in burrows dug in soil as opposed to nesting in matted *P. poiformis*. The average pre-fire soil depth is also not known, but in Colony B, which is very similar to pre-fire Colony A, shearwaters are able to use soil 150 mm or greater in depth for burrowing (provided *P. poiformis* is present to maintain soil stability). Thirty-one randomly selected points throughout Colony B averaged 189 mm soil depth (range 100–340 mm).

Predicting when soil in Colony A will have reformed to similar depth is difficult because in 1989, when measurements were taken, the average soil depth in Plot 3 from 15 sites was 66 mm (range 25–105 mm). Presumably, *P. poiformis* contributes most to the formation of soil in such localities owing to the nature of the plant, and this species had only become firmly established two years earlier. In 1998, the average soil depth in this plot was 71 mm (range 25–113 mm). In comparison, in Plot 1, where *P. poiformis* was slow to establish, soil depth measured in 1989 averaged 39 mm from 15 measurement sites (range 15–75 mm). Even after sixteen years, soil depth in plot 1 still averaged the same order, 32 mm (range 15–96 mm).

The rate of soil build up is compounded by the contribution that increasing numbers of re-establishing nesting shearwaters will have to nutrient input and, therefore, plant growth rates (Brothers & Harris, pers. obs.).

Post-fire Shearwater Burrow Density

Seven years after the fire, average burrow density was only 0.46/m^2 with an occupancy rate of 48.5%, 16.2% less than the average occupancy rate (Skira & Wapstra 1980).

Shearwaters first returned to Plots 3 and 4 at Colony A in September 1988. Whilst there was still insufficient soil to permit burrowing, *P. poiformis* had now become sufficiently well established to form a protective canopy with a dense matted base that was adequate for shearwaters to attempt nesting. Canopy height was now a uniform 200 mm but 400 mm where burrowing occurred.

In Plots 3 and 4, burrowing attempts were recorded amongst matted *P. poiformis*. However, only one egg was laid in one plot (Plot 3) and this subsequently disappeared, presumably because it still had insufficient concealment from predators such as Tasmanian raven (*Corvus tasmanicus*), pacific gulls (*Larus pacificus*) and silver gulls (*L. novaehollandiae*). The incubating bird was only partially concealed in its burrow. In Plot 4 there was evidence of three burrowing attempts but no breeding followed.

The following season, there were six burrowing attempts in Plot 3, and three eggs were laid. From these, one chick successfully fledged, the first in eight breeding seasons. Plot 4 had three burrowing attempts with an egg laid in one and the chick successfully fledged. On pre-fire burrow density information, Plots 3 and 4 should each contain about 14 burrows which, based on information from Skira & Wapstra (1980), should produce about seven chicks annually, significantly more than that recorded after eight breeding seasons following the fire. In 1989, four chicks were raised successfully from 50 attempts at burrowing throughout Colony A.

Penguins attempted to reuse all plots for nesting in the 1984 breeding season and did so successfully in Plots 3 and 4 from 1986 onward. This species is not strictly colonial in its nesting habits, so can take advantage of the smallest amount of suitable nesting habitat.

By 1989, only one pair of prions had re-established in Plot 4 and none in any other plot.

Shearwaters displaced by the fire also attempted to re-establish, but suitable habitat was not available. The invasion of shearwaters from Colony A to Colony B caused considerable damage to Colony B (pl. 3). Prior to the fire

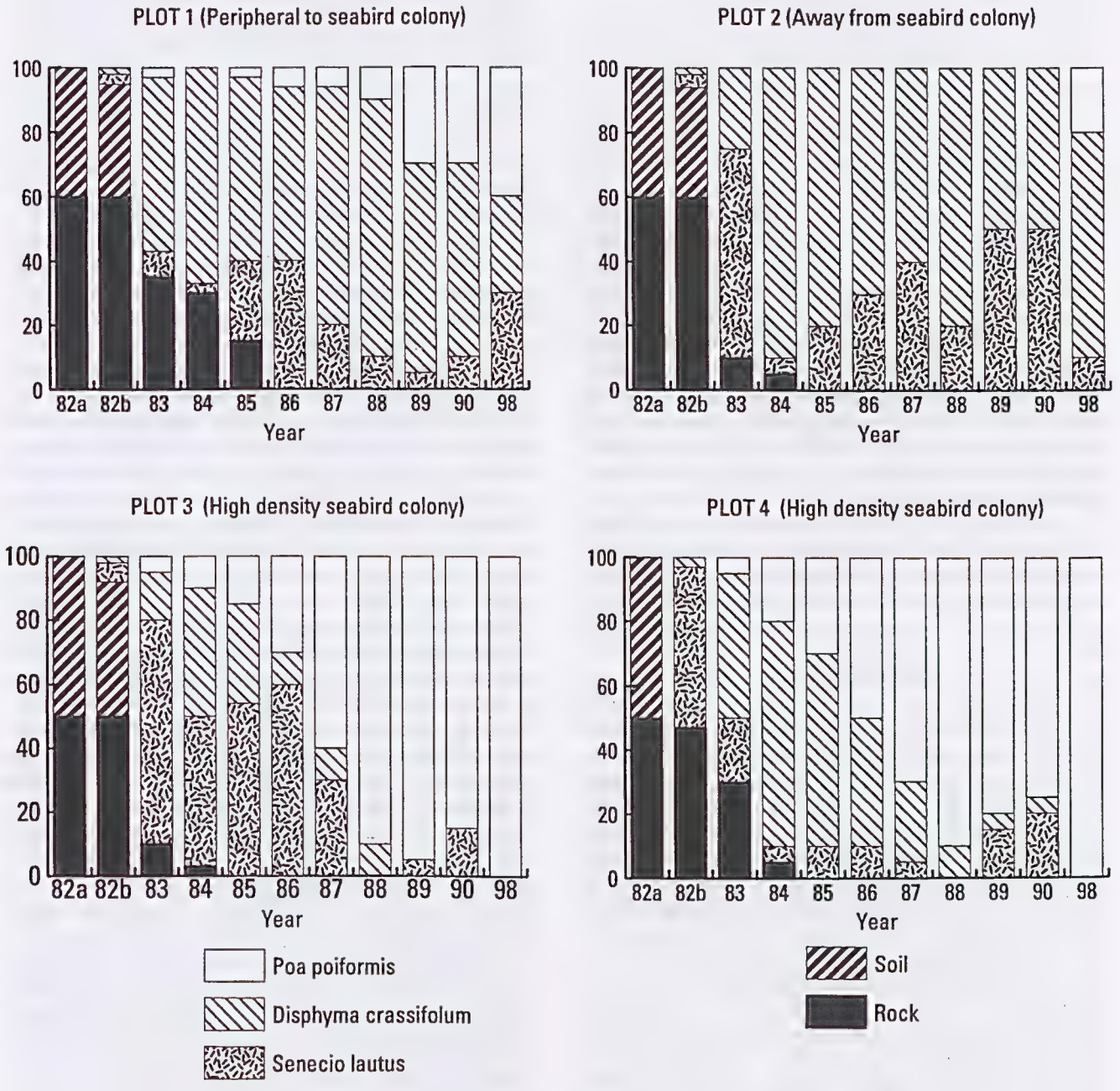


FIG. 3 — Total additive cover percentage of dominant species, soil and rock, measured at four sites between 1982 and 1998.

Colony B was densely covered in *P. poiformis* with scattered *S. lautus*. Burrowing habitat was stable. The invasion of Colony B by Colony A birds was not apparent in November 1982, but by mid January 1983 most of Colony B had been seriously damaged by excessive burrow-making. Most shearwater burrows were either empty or contained courting pairs of shearwaters. Presumably, competition for burrows was so intense that breeding attempts had failed.

By the following breeding season (1984) damage to vegetation was severe, with *P. poiformis* remaining in only isolated clumps, between which was bare soil no longer capable of supporting burrows, due to its fragility in the absence of plant root systems. Each evening, hundreds of adult shearwaters could be seen sitting on the surface, no longer making burrows to occupy. By the 1988 breeding season, destructive activity had diminished; *S. lautus* was flourishing in bare soil areas, with evidence of new *P. poiformis* growth. Burrow density had decreased by then from a pre-fire average of 0.59/m^2 to 0.15/m^2, or from about 350 to 90 burrows. The decrease in destructive activity in Colony B coincided with the return of shearwaters to Colony A. Their return to Colony A, however, does not altogether explain the reduced damage, because only small numbers of birds are known to have returned to Colony A.

Inter-island Comparisons

The shearwater colony on Little Dog Island (fig. 1) was estimated to contain 352 000 burrows (Brothers & Skira 1988), with an average occupancy rate by chicks of 64.7% (Skira & Wapstra 1980). In early 1973, the whole colony was burned. Of 100 shearwater burrows examined several days after the fire, in March 1973, only 19 still contained chicks. Therefore, based on the average occupancy rate, 71% of chicks or 161 900 died.

A number of dead adult shearwaters were also found in the colony but significant numbers would not have perished, because at this time of year few remain ashore during day time.

Once again, as at Albatross Island, the fire on Little Dog Island caused the least long-term damage to the shearwaters, owing to the fact that mostly chicks and not adults were involved. This was not the case on Cat Island (fig.1), where a fire that burned virtually the whole shearwater colony, in addition to an Australian gannet (*Morus serrator)* colony, occurred in early January 1984, at which time adult shearwaters were incubating. No occupied burrows were found here several days after the fire (pl. 4).

Forty-five or 33% of the 136 shearwater colonies listed in Naarding (1981) have been burnt in the last 15 years (see appendix), many of these more than once. This amounts to approximately 52% by area of shearwater colonies.

DISCUSSION

In terms of shearwater numbers affected, the fire on Albatross Island, although significant for this particular location, was of little consequence generally, because of the very large Tasmanian population distributed through many rookeries. Documenting the direct and indirect effects of this particular fire revealed some unexpected problems that fires can cause shearwaters. These are mostly due to the total destruction of nesting habitat, which is not typical of fires generally in shearwater colonies (N. Brothers, pers. obs.). Fires frequently burn rapidly through shearwater colonies, destroying all existing vegetation but causing little damage to soils. In such circumstances, existing *P. poiformis* tussocks are capable of regrowing. Nevertheless, such fires still cause considerable shearwater mortality.

For the prions, we think that there were adequate available nesting sites elsewhere on the island for those prions displaced by the fire to have re-established. This would account for them not making use of the area at the earliest opportunity. This supposition is supported by the observation of a significant increase in courting pairs of prions in nesting habitat adjacent to the burnt area that did not attempt breeding on the first and second seasons following the fire. The abundance of such birds subsequently diminished, presumably as they established new nesting sites.

The shearwaters' synchronised breeding habits, in common with many other species of seabirds, makes them particularly vulnerable to fires. If a fire should occur any time during the incubation period, it is highly likely that one bird of each pair will die and no chicks will be produced that year. It is possible that a high proportion of those killed will be of the same sex, owing to the synchrony of both egg-laying and subsequent parent-to-parent incubation shifts by adults. Apart from the fact that most shearwaters mate for life (unless their partner dies), the result of high adult death rate during incubation would be long-term disruption to the productivity of the colony. Such effects have not yet been studied, although the scant data available from Cat Island before and after the fire do give an indication of long-term effects of a fire occurring at a time when the greatest long-term damage to shearwater was likely. Warham (1979) assessed the burrow density on Cat Island before the fire at about $1/m^2$. Shearwaters and many other procellariforms cannot easily compensate for such dramatic high death rates of either adults or chicks, as each pair is only capable of producing one egg each year.

It could take many generations for a shearwater colony in which large numbers of adult birds died to regain normal productivity (Serventy & Curry 1983). This would be especially so if, in normal circumstances, a colony's annual recruitment is equal to annual natural mortality. *Puffinus tenuirostris* is capable of breeding at five years of age (Serventy 1967) but most do not do so until about seven years of age (Skira 1991). Such factors as nesting-site availability could affect the average age of first breeding, so the death of large numbers of breeding adults in a fire may provide the opportunity for significantly more birds to commence breeding at a younger age. This is one way the species can increase productivity. Another way is by maintaining higher than average chick survival, which is not likely to be related to the effects of fires.

Like most burrow-nesting species of seabirds, shearwaters are particularly disinclined to emerge from the safety of burrows during daytime. As virtually all fires are lit during daytime and tend to burn very quickly through colonies, few adult shearwaters are likely to escape. Some appear to escape their burrows but experience difficulty in becoming immediately airborne from densely vegetated areas. The abundance of burned adults on the colony surface at the Cat Island fire is evidence of this. It was apparent during burrow inspection after the fire on Little Dog Island that survival of burrow occupants increased on sloping ground, where the burrows tend to be deeper and also the passage of fire could be more rapid (if the fire was burning uphill).

Destruction of nesting habitat, as occurred on Albatross Island, is another long-term consideration. Generally recurrence of a fire on a seabird breeding island is rare or at least irregular, which reduces considerably the likelihood of colony degeneration as a consequence of fire. Fire was a commonly used method of improving access to shearwater burrows, by reducing plant density, on islands subjected to commercial harvesting of shearwater chicks. It is still used today but not as frequently. Such fires to reduce *Poa poiformis* density were lit outside the breeding season and were actually considered to increase burrow densities.

However, it is more likely that the increase was an illusion created by burrows being more readily visible to bird harvesters. Such deliberate burning during winter, when birds are absent, is likely to have less impact on burrowing habitat than would a summer fire because, during winter, the soils tend not to burn, as they are invariably wet. This also means that the tussock roots are not killed, so regrowth is comparatively rapid, which prevents colonisation by plant species such as *Senecio capillifolius.* This species as well as *S. lautus* colonise disturbed areas rapidly in the environment of shearwater colonies. These plant species show a marked annual senescence and have less effective root systems than *P. poiformis* for stabilising soils and preventing excessive soil disturbance by birds. The *Senecio*

species are less effective at preventing soil erosion in shearwater colonies, most of which are exposed to frequent, strong winds. *S. capillifolius*, which is apparently restricted to shearwater colonies (Kirkpatrick 1993), is possibly a fire ephemeral (Guiler *et al.* 1958).

Over a prolonged period, such fire management would undoubtedly have decreased shearwater burrow density through increased soil instability. This was noticeable even after one fire on both Little Dog and Cat Islands.

A number of shearwater breeding islands are also used for sheep and cattle grazing, and fire is used to generate new plant growth, so burning often occurred with no consideration for breeding seabirds. This practice is fortunately becoming less frequent.

The fire history of all shearwater colonies in Tasmania is very poorly documented, so it is not always possible to ascertain whether certain colonies were burnt, and if so when. There are several instances where it appears obvious that burrowing habitat degradation similar to that on Albatross Island has been caused by fire, yet no records exist of recent fires, nor are there prior burrow-density assessments from which population estimates could be made for comparison.

The likelihood of a colony being burnt is influenced by the following factors. It is highly likely that any colony on mainland Tasmania, as opposed to offshore islands, will be burnt and perhaps more frequently than once in ten years. If adjacent to residential establishment, as a number of colonies are, the likelihood of fires is reduced. This is also true of those colonies on offshore islands where man has a "presence", such as lighthouses or other shipping navigation aids. Other colonies on offshore islands are protected somewhat from being burnt simply because they are remote and difficult for persons to visit. These localities contrast with those that are visited often by boat for recreational purposes.

SUMMARY

Fire on Albatross Island (1982) destroyed a colony of short-tailed shearwaters, incinerating at least 900 chicks. Some penguins died, but thousands of fairy prion chicks which fledge in February escaped destruction by a matter of weeks.

For the present study, post-fire vegetation recolonisation and soil formation were measured over 16 years at four plots on Albatross Island, and a succession of species was observed. One of the plots was indistinguishable from unburnt similar habitat on the island in its third year of regeneration. *Poa poiformis* and *Senecio lautus* were observed to be the climax species on this rookery. Over a nine-year period, four plots in burned vegetation on Albatross Island went from bare ground and soil to 100% *Poa poiformis* cover in two cases, a mixture of *Poa poiformis, Disphyma crassifolium* and *Senecio lautus* dominating the remaining two plots. Soil depth was found to increase rapidly where *Poa poiformis* was able to establish early dominance.

Differential recolonisation success, recorded amongst shearwaters, fairy prions and fairy penguins, was related to soil and vegetation recovery.

After the fire, fairy penguins successfully sought nesting sites elsewhere on the island, outisde the burnt area. Penguins slowly began to recolonise the burnt area two years after the fire, because they can exploit the smallest amount of nesting habitat.

Shearwaters displaced by the fire from Colony A sought to nest in unburned Colony B, causing considerable damage to soil and vegetation. Competition for burrow space became so severe that breeding was probably affected. Six years after the fire, destructive activity diminished.

The effect of the fire on birds on Albatross Island was compared with a colony on Little Dog in the Furneaux Group. After the whole colony was burned in 1973, it was estimated that 71% of the chicks died. A large number of adults did not perish, because few adult shearwaters remain ashore during the day at this time of the year. As at Albatross Island, this fire caused the least long-term damage to shearwaters because mostly chicks were burned and not adults. In contrast, a fire on Cat Island in January 1984, completely destroyed the colony because the adult shearwaters were incubating.

Considerable mortality of birds can occur because of the shearwaters' synchronosed breeding habits. This makes them, in common with other species of seabirds, particularly vulnerable to fires. The long-term effect could be significant because each adult pair is only capable of producing one egg each year. A population could partly compensate by commencement of breeding at a younger age, and by maintaining higher than average chick survival.

Fires can cause total destruction of shearwater rookery habitat, but many deliberately lit fires in rookeries are cool winter burns which destroy standing vegetation but not soil or root structures. Burning muttonbird rookeries does not increase burrow density, but makes existing burrows more readily visible. Over a prolonged period, the winter burns decrease shearwater burrow density through increased soil instability.

Forty-five of Tasmania's 136 shearwater colonies have been burnt in the last 15 years, many of these more than once.

An assessment of risk of burning of all Tasmanian shearwater colonies shows that 21% of colonies are at high risk of being burnt, 26% are at moderate risk and 52% are considered to be at low risk of burning.

ACKNOWLEDGEMENTS

We thank the Toyota Foundation for their support of this project through the co-ordination of Professor N. Maruyama of Tokyo University of Agriculture and Technology. Neil Smith provided transport on *Wild Wind* to Albatross Island, without which the study would not have been possible. We thank all those who accompanied Nigel on the numerous visits to Albatross Island; your support and participation is appreciated. Irynej Skira undertook burrow occupancy assessment on Cat Island, information from which was included in this paper.

REFERENCES

Brothers, N.P. & Skira, I.J., 1988: Little Dog Island, Furneaux Group, Tasmania — Seabird Island No. 185. *Corella* 12: 78–84.

Brown, M.J., Maruyama, N. & Williams, K.J., 1993: Ecological studies of vegetation in short-tailed shearwater colonies in Tasmania. *Pap. Proc. R. Soc. Tasm.* 127: 11–16.

Gillham, M.E., 1960a: Vegetation of tern and gannet colonies in northern New Zealand with a comparative note on

colonies in Bass Strait, Tasmania. *Trans. R. Soc. NZ* 88: 211–234.

GILLHAM, M.E., 1960b: Destruction of indigenous heath vegetation in Victorian sea-bird colonies. *Aust. J. Bot.* 8: 278–317.

GUILER, E.R., SERVENTY, D.L. & WILLIS, J.H., 1958: The Fisher Island field station - with an account of its principle flora and fauna. *Pap. Proc. R. Soc. Tasm.* 92: 165–174.

KIRKPATRICK, J.B., 1993: Dry coastal ecosystems of southeastern Australia. *In* van der Maarel, E. (Ed.): *ECOSYSTEMS OF THE WORLD 2B. DRY COASTAL ECOSYSTEMS: AFRICA, AMERICA, ASIA AND OCEANIA.* Elsevier, Amsterdam: 273–288.

NAARDING, J.A., 1981: Study of the Short-tailed Shearwater, *Puffinus tenuirostris* in Tasmania. *Wildl. Div. Tech. Rep.* 81/3. National Parks and Wildlife Service, Tasmania.

PLOMLEY, N., 1966: *FRIENDLY MISSION: THE TASMANIAN JOURNALS AND PAPERS OF GEORGE AUGUSTUS ROBINSON 1829-1834.* Tasmanian Historical Research Association, Hobart.

SERVENTY, D.L., 1967: Aspects of the population ecology of the Short-tailed Shearwater, *Puffinus tenuirostris. In* Snow, D.W. (Ed.): *PROCEEDINGS OF THE XIV INTERNATIONAL ORNITHOLOGICAL CONGRESS.*

SERVENTY, D.L. & CURRY, P.J., 1983: Observations of colony size, breeding success, recruitment and inter colony dispersal in a Tasmanian colony of Short-tailed Shearwaters, *Puffinus tenuirostris* over a 30 year period. *Emu* 84: 71–79.

SKIRA, I.J., 1991: The Short-tailed Shearwater: A review of its Biology. *Corella* 15: 45–52.

SKIRA, I.J. & WAPSTRA, J.E., 1980: Occupation of burrows as a means of estimating the harvest of Short-tailed Shearwaters in Tasmania. *Emu* 80: 233–238.

WALSH, D., KIRKPATRICK, J. B. & SKIRA, I.J., 1997: Vegetation patterns, environmental correlates and vegetation change in a *Puffinus tenuirostris* breeding colony at Cape Queen Elizabeth, Tasmania. *Aust. J. Bot.* 45: 71–79.

WARHAM, J., 1979: Cat Island, Tasmania — Seabird Island No. 68. *Corella* 3: 42–45.

(accepted 5 July 1999)

APPENDIX

Tasmanian shearwater rookeries (and their areas) where there has been observed evidence of burning. The list begins with islands in the Furneaux Group, thereafter proceeding clockwise around Tasmania.

Cat Island	2 ha	Spectacle Island	1 ha
Little Green Island	2 ha	Betsey Island	20 ha
Big Dog Island	40+ ha	Cape Queen Elizabeth (north side)	1 ha
Little Dog Island	15 ha	Cape Queen Elizabeth (main rookery)	9 ha
Passage Island	100 burrows	Pineapples	5 ha
Preservation Island	1000 burrows	Southport Island	v.small
Chappell Island (part)	10 ha	Actaeon Islands	5 ha
Big Green Island	2 ha	Cape Sorell (Trumpeter Rock)	12 ha
Kangaroo Island	2 ha	Ocean Beach, Strahan	10 ha
Prime Seal Island	very few	Hunter Island North	6 ha
Settlement Point	2 ha	Hunter Island South	5 ha
Outer Sister Island	800 burrows	Three Hummock Island	140 ha
Inner Sister Island	1500 burrows	Walkers Island	56 ha
Swan Island	1 ha	Robbins Island (SE)	4 ha
George Rocks (off Eddystone)	150 burrows	Robbins Island (N)	2.5 ha
St Helens Island	1000 burrows	The Nut, Stanley	v. small
Lachlan Island		Ninth Island	1.5 ha
Blowhole, Maria Island	11 ha	Waterhouse Island (N)	0.5 ha
Tasman Island (& adjacent mainland)	1 ha	Hunter Island West	2.5 ha
Wedge Island	10 ha	Albatross Island	v. small
Sloping Island	20 ha	Christmas Island	7.5 ha
Smooth Island (Dunalley)	18 ha	New Year Island	25 ha
Fulham Island (Dunally)	2 ha		

DISTRIBUTION AND CONSERVATION STATUS OF THE MT MANGANA STAG BEETLE, *LISSOTES MENALCAS* (COLEOPTERA: LUCANIDAE)

by Jeff M. Meggs and Robert J. Taylor

(with one table, two text-figures and one plate)

MEGGS, J.M. & TAYLOR, R.J., 1999 (31:x): Distribution and conservation status of the Mt Mangana stag beetle, *Lissotes menalcas* (Coleoptera: Lucanidae). *Pap. Proc. R. Soc. Tasm.* 133(1): 23–28. ISSN 0080–4703. Forestry Tasmania, PO Box 343, Devonport, Tasmania, Australia 7310, formerly Forest Practices Board (JMM); Forestry Tasmania, 79 Melville Street, Hobart, Tasmania, Australia 7000 (RJT).

Lissotes menalcas (the Mt Mangana Stag Beetle) is an obligate log-dwelling beetle and is presently classified as vulnerable under the Tasmanian *Threatened Species Protection Act* 1995. The distribution, habitat and conservation status of this species were investigated through a combination of collation of known locations and searches for the species in decaying logs across likely areas of occurrence. *L. menalcas* was found to have a wide distribution in southeastern Tasmania and is now recorded from 34 localities. The species was found in a variety of wet forest habitats from old-growth mixed forest through to 23-year-old wet eucalypt silvicultural regrowth. About 12% of wet eucalypt forest within the predicted range of *L. menalcas* is formally reserved, and another 14% on Crown land is unlikely to be subject to logging. *L. menalcas* appears to tolerate both wildfire and clearfelling with regeneration burning. Because the species depends on an ongoing supply of rotting logs for its long-term survival, plantation development will probably lead to the elimination of the species from such areas. Analysis of the likely impact of plantation establishment within its range over the next ten years indicates that it will not reach levels that would lead it to be considered as vulnerable. Thus, it is recommended that the status of the species be changed from vulnerable to rare. However, there is a need to determine the ecological sustainability of present forest management practices in relation to the decaying-log habitat and to continue to monitor the extent of clearing and modification of the species' habitat.
Key Words: *Lissotes menalcas*, stag beetle, threatened species, conservation, plantations, wet eucalypt forest, Tasmania.

INTRODUCTION

The Mt Mangana Stag Beetle *Lissotes menalcas* Westwood is a large, black, flightless beetle, the males of which have large mandibles (pl. 1). Its body length varies between 16 and 25 mm. It is endemic to Tasmania and readily distinguished from other Tasmanian lucanids by the following features: a highly polished exoskeleton, causing the males to appear as if coated with black enamel; a peculiarly shaped prothorax, with a humped or peaked appearance, and a largely excavated head (Lea 1910). The female is also highly polished but not as shiny as the male, due to the much denser and larger punctures on the head and prothorax. *L. menalcas* is a relatively long-lived beetle (five to six years, including larval stages — G. Bornemissza, pers. comm.). It is believed to spend the majority of its life within decaying logs feeding on wood-rotting fungi.

L. menalcas was first collected prior to 1855 (Westwood 1855). Previous to this study, it was only known from a handful of sites in southeastern Tasmania (Jackson & Taylor 1994). *L. menalcas* was classified as vulnerable under the Tasmanian *Threatened Species Protection Act* 1995, due to the small number of recorded localities and its apparent disappearance from some of these localities, not having been re-collected from these since early this century.

Meggs (1996) has shown that first rotation logging has little influence on the size or quantities of decaying logs or the types of rot present. However, with successive rotations on an 80-year or shorter cycle, it is likely that the volume and size of logs available would decline. Studies in Europe and North America of sites which have been subject to intensive forest operations over several rotations have documented a dramatic reduction in the volume of rotting-log resource, particularly large diameter logs (Gore & Patterson 1986, Andersson & Hytteborn 1991) and late-stage rotting logs (Bader *et al.* 1995), which are important habitat for a number of beetle families including Scarabaeidae, Lucanidae and Passalidae (Harmon *et al.* 1986).

PLATE 1
Lissotes menalcas *adult male, dorsal view (body length is 20 mm, excluding the mandibles).*

Given the cryptic habits of the species, it was suspected that it was probably more widespread than indicated by the available records. However, because of its log-dwelling habit and the potentially high proportion of its range occurring in wood-production forests, the species could be at risk. The present study was thus undertaken to reassess its distribution and conservation status.

METHODS

Records of the species were collated from museum and private collections. Fieldwork was conducted in southeastern Tasmania between November 1995 and April 1996 and in May 1998 at 43 sites. All sites searched were in wet eucalypt or mixed forest. These forest types were targeted so as to

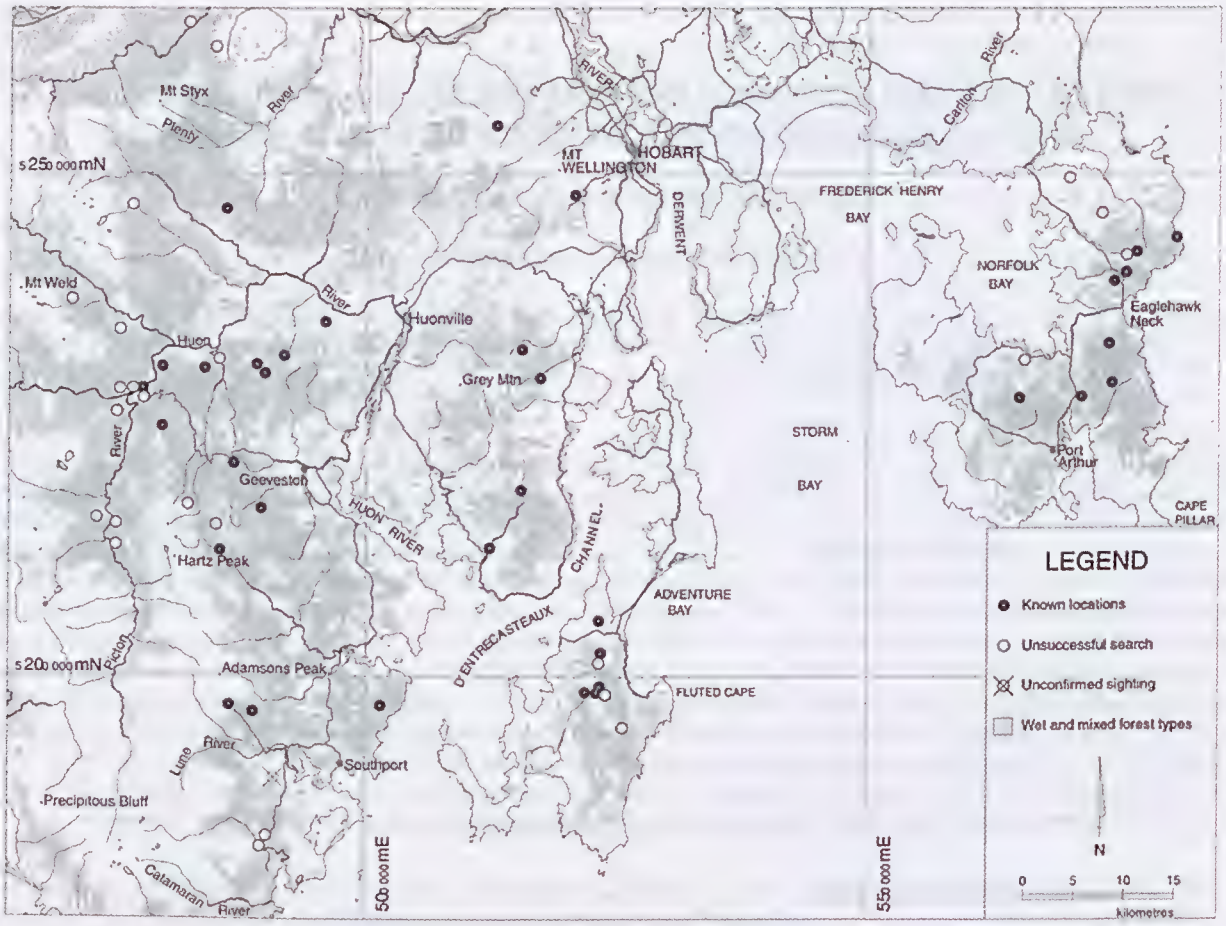


FIG. 1 — Known locations for Lissotes menalcas, *sites of unsuccessful searches during this study and distribution of wet eucalypt forest in southeastern Tasmania.*

maximise our chance of finding the species in an area. Rainforest was not searched, but the species is likely to occur in this forest type, as it has been found to occur in rainforest logs in mixed forest. We did not test our assumption that the species does not occur in dry forests but felt this was unlikely, given that all museum and private records were from wet forest.

Because of its cryptic habit, the sampling method used to locate *L. menalcas* was destructive and involved breaking open logs and searching the interior for adults. Logs lying on the ground as well as elevated logs of all sizes were searched. The only selection criterion used was that the exterior of the log exhibited signs of decay, including visible rot at the end or at a split, or a well-developed moss covering, suggesting that the log had been down for some time. More intensive searching was undertaken in those logs which contained moist red rot, a type of wood-decay which *L. menalcas* was thought to prefer (G. Bornemissza, pers. comm.). If white rot was encountered, the entire log was not searched, only the section that was broken. White rot tended to be either very fibrous or very wet and pulpy; hence, it tended to fall apart and did not require the detailed searching that red rot did. Sites were searched until *L. menalcas* was found or two hours had elapsed. Because of the destructive sampling method, no searches were permitted in reserves controlled by the Parks and Wildlife Service.

Traps were set at two known localities of *L. menalcas* in the southern forests, to determine whether standard pitfall trapping was a reliable sampling method for this species. Each trap consisted of a plastic cup (diameter 85 mm) with ethylene glycol as a preservative placed inside a buried section of PVC pipe so that the rim of the cup was flush with the soil surface. Traps (16 at one site and 20 at the other) were set at least 2–3 m apart, as close as possible to decaying logs. Traps were left in place for 12 weeks from early December and were emptied at six weekly intervals.

Habitat data (vegetation, leaf litter, soil, geology, numbers and sizes of logs, slope, aspect, altitude, presence of fire scars on standing or fallen trees and any evidence of logging) were collected at all known localities of *L. menalcas,* except two sites that have been logged or burnt since the specimen was recorded, four without precise locality details, or one to which access could no longer be obtained.

The environmental modelling package CORTEX (Peters & Thackway 1998), which has been derived from BIOCLIM (Busby 1991) and GARP (Stockwell 1993), was used to predict the potential area where suitable environmental conditions occurred for *L. menalcas.* Ten environmental variables determined at a scale of 1 km grid squares were used in the model: two temperature, two rainfall, soil nutrient level, geology, slope, aspect, topographic position and elevation. The model constructs environmental envelopes from combinations of ranges and/or categories

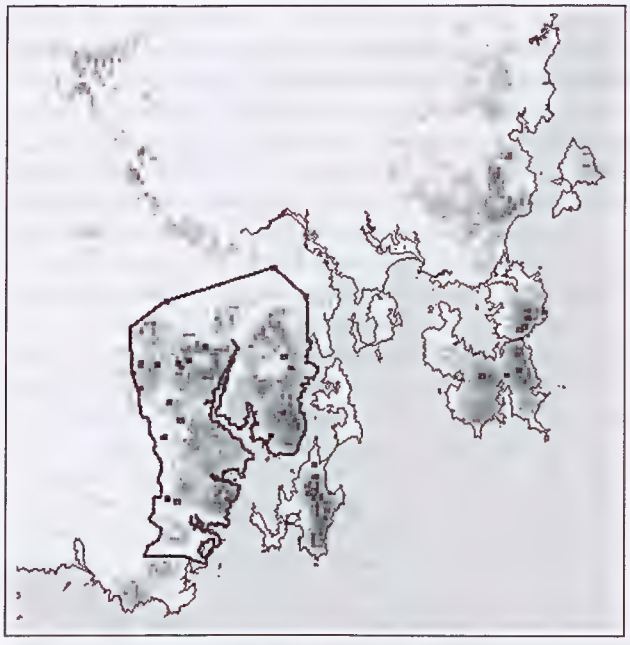


FIG. 2 — Predicted distribution of suitable environmental conditions for Lissotes menalcas *in Tasmania from the CORTEX environmental modelling package. The darker the shade of grey the higher the predicted suitability of the environment. The black squares are known locations. Further sites of predicted suitability occurred in more northern areas of eastern Tasmania which are not shown. The black line represents the proposed limits of the predicted distribution in the mainland region.*

of variables which imply the presence of the species. This analysis was undertaken in the Parks and Wildlife Service GIS section. The predicted range of the species was determined, based on the following: the results of the CORTEX model, the proximity to known locations, the presence of known sampling areas and the extent of suitable habitat present. The results of the CORTEX model were only used as one of the guides to predicting the distribution, as factors other than those used in the model may determine a species distribution. It is not uncommon for an invertebrate species not to occur in parts of the environmental range predicted by a CORTEX model, when these are searched for the species (Meggs 1999).

RESULTS

Distribution

Lissotes menalcas was found to have a wide distribution in southeastern Tasmania (fig. 1). In addition to the six localities known prior to this study (Jackson & Taylor 1994), a further 12 records were obtained from private collectors and institutions, and another 16 were obtained by searching. *L. menalcas* has now been recorded at 34 localities, with an additional unconfirmed record from Ida Bay. This record was obtained from a list of Tasmanian Lucanidae produced by Barry Moore and provided to George Bornemissza. Locations were given, but grid references were not included. The discovery of this species on the Tasman and Forestier Peninsulas has extended its range east by just over 40 km, representing a significant increase in its known distribution (fig. 1).

The extent of occurrence of *L. menalcas,* measured as the land area within the smallest convex polygon which contains all the sites of occurrence (calculated separately for the southern forests, South Bruny and the Tasman and Forestier Peninsulas combined), is 1831 km^2. The CORTEX model (fig. 2) showed suitable environment for the beetle occurring in many areas well to the north and south of the known locations. Our conservative predicted extent of occurrence (fig. 2) was 3068 km^2.

Pitfall trapping proved to be an unreliable method for sampling *L. menalcas.* During a 12-week period, with a total of 36 traps laid at two localities at which the species was known to occur, only one female *L. menalcas* was trapped.

No data are available on population sizes. Three areas of high population densities in the Southern Forests were reported by private collectors. At these locations up to 10–12 *L. menalcas* have been found in a single log (G. Bornemissza, M. Bouffard and A. Vanderschoor, pers. comm.).

Habitat Requirements

At sites where the species occurs, annual rainfall varies from just under 700 mm (on the Forestier Peninsula) to just over 1220 mm (in the Wellington Ranges). *L. menalcas* was found at altitudes up to 600 m, but no sites over 650 m were searched in this study, although suitable vegetation occurs up to approximately 850m. Slightly less than half (15 out of 34) of the recorded localities of *L. menalcas* occur on Jurassic dolerite. The remaining records occur on a variety of sedimentary rock types. Soils were generally clay loams.

Leaf litter composition and depth varied greatly both within and between sites. *L. menalcas* was found in both wet eucalypt forest and mixed forest, but was found more frequently in the former (70% compared with 35%; χ^2=6.3, $p<0.05$). Sites differed markedly in floristic and structural composition and successional stage (ranging from even-aged wet eucalypt regrowth forest to mixed age, late successional mixed forest). Sites were dominated by either *Eucalyptus regnans, E. globulus* or *E. obliqua. L. menalcas* was found in all three of the natural regrowth sites searched and three of the four silvicultural regrowth forest sites.

During this study, one female was found in white, pulpy rot inside a sassafras *Atherosperma moschatum* log. All other *L. menalcas* found occurred in eucalypt logs, either just below the surface in slightly rotten logs or deep within the core of well-rotted logs. Generally the rot was a dark red and had a moist, clay-like consistency. This rot type does not appear to occur in rainforest trees. There was some variation in colour and wetness, from less moist orange-red rot through to saturated brown humus-like rot. However, only dead specimens were found in the latter. *L. menalcas* has also been collected from myrtle *Nothofagus cunninghami* logs (G. Bornemissza, pers. comm.) and from under wood debris in a sawdust mound at the site of an old timber mill (A. Vanderschoor, pers. comm.).

Three of the recorded localities were severely burnt in the late 1960s by wildfire, which completely removed the canopy species present. At one of the sites, even small drainage lines and gullies appear to have been burnt, discounting the possibility of *L. menalcas* surviving in unburnt refuges. The silvicultural regrowth forest sites where *L. menalcas* was present would have been regenerated by a high intensity burn.

Distribution by Land Tenure and Land Use

Twenty-three (68%) of the 34 known locations for *L. menalcas* occur on land at present under the management of Forestry Tasmania. Seven of these are in areas which are, or are soon to become, dedicated reserves (Abel Tasman Forest Reserve, Tahune Forest Reserve, Mt Mangana, Hastings Caves–Southwest National Park extension, Lonnavale 1). Of the other known locations managed by Forestry Tasmania, nine are planned for wood production, one of which has been logged since the species was found there, and the remaining seven are in management zones protected from logging operations. Eight sites occur on private property. The remaining three sites are in reserves managed by the Department of Primary Industries, Water and Environment (Wellington Park, Snug Falls Nature Recreation Area).

The percentage of the habitat which is under different tenures or projected land uses is roughly comparable in the three major regions inhabited by the species (mainland, South Bruny, Tasman and Forestier Peninsulas), and so only the overall figures are presented in table 1. The figures for rainforest are presented separately from wet eucalypt forest as, although some of these areas will support *L. menalcas,* it is unlikely that densities would be as great, due to the apparent preference of the species for eucalypt logs. Hence, the values for the wet eucalypt forests (which include sites with a rainforest understorey) are most relevant to assessing the amount and likely future of habitat of the species. These figures are derived from the vegetation mapping undertaken for the development of the Tasmanian Regional Forest Agreement and are applicable as at June 1996. Prior to this date, 35 km^2 from the area of occurrence and 48 km^2 from the predicted range had been converted to plantation on State forest and, hence, would not have been counted in the area of habitat figures in table 1. All of these plantations have been established on sites formerly supporting wet forest. Between the time of the production of the forest vegetation map for the Regional Forest Agreement (June 1996) and March 1999, for wet forest habitat 431 ha within the area of occurrence and 905 ha within the predicted range were converted to plantation. Thus, to date, plantation development has reduced the area of wet eucalypt forest on Crown land by 5.4% in the area of occurrence and 5.0% of the predicted range from the Crown land estate. No estimates are available on how much habitat has been cleared from private land. *L. menalcas* has 134 km^2 (12%) of wet eucalypt forest habitat reserved across its predicted range and a further 161 km^2 (14%) in State forest which is unlikely to be subject to logging.

DISCUSSION

Distribution

This study has substantially extended the known range of *L. menalcas* in southeastern Tasmania to the Forestier and Tasman Peninsulas. The rediscovery of *L. menalcas* in the Wellington Ranges is important, as it had not been recorded there since early this century (Lea 1910). Together, these findings have increased the known range of the beetle by more than 25%.

The distribution of *L. menalcas* may be greater than is currently known. The environmental domain for the species predicted from the CORTEX model indicated that a suitable environment exists in many areas outside the current known range. However, this study presents a conservative subset of this domain as a potential distribution for the species. This predicted distribution needs to be tested by further sampling of areas that the CORTEX model deemed to be environmentally suitable which we have not included.

On South Bruny Island and the Tasman and Forestier Peninsulas, all of the predicted areas were considered to be likely for *L. menalcas.* The predicted southern mainland boundary was conservatively taken to be the D'Entrecasteaux River, based on an unconfirmed record from Ida Bay. However, a suitable, predicted environment and habitat is present south of the D'Entrecasteaux River, and further searches could possibly find the species in this area. The predicted western boundary was determined on the basis of the known locations, the presence of suitable habitat and the climatic predictions. The predicted northern boundary was based on the known locations, as there was no evidence provided by the climatic model that they would occur further north in that particular region.

It is unlikely that the species occurs in the Wielangta area, as predicted by the CORTEX model, as much searching conducted by several investigators (J. Meggs, K. Michaels, G. Bornemissza, M. Bouffard, G. Blake, pers. obs. and pers. comm.) has failed to reveal its presence. However, the northwestern limit delineated in figure 2 could be extended with further searching. Although two searches in the Styx and West Uxbridge areas failed to locate the species, the Florentine and Mt Field areas remain to be searched.

To our knowledge, only one specimen additional to the one captured in this study has ever been caught in a pitfall trap. This was by R. Bashford (pers. comm.) in 1996 near the Kermandie River using the same type of pitfall as in our study. The very low capture success of these traps indicates that pitfall trapping is not a suitable means of sampling populations. In a study of the threatened stag beetle *L. latidens* in eastern Tasmania, Michaels (1996) also found lucanid species that were not captured in pitfall traps by searching for them in logs. Direct sampling appears to be the most reliable method available to locate *L. menalcas.* Unfortunately, the log-dwelling habit of *L. menalcas* makes direct sampling a destructive, time-consuming and serendipitous sampling method.

Habitat Requirements

Lissotes menalcas was found in a broad range of wet forest communities ranging from old-growth mixed forest to 23-year-old wet silvicultural regrowth forest. Because it was also found in rainforest species logs, albeit at lower rates than in eucalypts, it is highly likely that it also will occur in rainforest. Because *L. menalcas* is an obligate log-dweller, its occurrence and population density will be influenced by the size and abundance of logs and the extent and type of log decay. Further research is required to elucidate the particular microhabitat within decaying logs preferred by *L. menalcas* and to quantify differences in the availability of such microhabitat in forests of different types and ages.

In wet forests that *L.menalcas* inhabits, clearfelling followed by an intense regeneration burn is the standard silvicultural treatment. The species appears to be able to survive this type of disturbance. In the sites with silvicultural

TABLE 1
The percentages of wet eucalypt forest and rainforest present in different land tenures and land use categories for the range of *Lissotes menalcas*

	Wet eucalypt		Rainforest	
	Known extent*	Predicted extent†	Known extent*	Predicted extent†
Percentage of habitat				
Crown land				
formal reserve	11	12	46	65
not to be logged‡	13	14	29	20
production forest	51	49	23	14
Private land (%)	25	25	2	1
Area of habitat (km²)				
mainland	671	867	21	43
South Bruny	2	72	0	<1
Peninsulas	45	193	1	1
Total	718	1132	22	45

* The extent of occurrence is the smallest convex polygon encompassing all of the known locations. Polygons were constructed separately for the three regions.
† The predicted distribution is based on the known locations, the extent of suitable habitat and the predicted occurrence of suitable environments from the CORTEX environmental modelling software.
‡ The area of Crown land not to be logged is made up of areas of State forest which are either informal reserves or have not been placed into coupes earmarked for production forestry.

regrowth, three of the four logs in which *L. menalcas* was located would have been present on the forest floor prior to logging. Most of the logs present as a result of logging did not appear to have decayed enough to have produced suitable habitat for *L. menalcas*. The protection afforded by the log habitat, at least in the larger logs, may be sufficient to insulate the species not only from the destructive effects of fire but also from the drying effects of the absence of a forest canopy in the years it takes a substantial canopy of regrowth to develop. However, the possibility of re-invasion of the logged area, following disturbance from logging and burning, cannot be ruled out. Anecdotal evidence that log-dwelling fauna survive burning is provided by Mesibov (1988: 20):

> In the course of my fieldwork I broke open literally hundreds of old eucalypt logs with jagged, burned ends and a hard, blackened surface, to find inside a mass of moist, unburned wood rot and a teeming community of invertebrates.

Fauna in the deep layers of soil are less affected by regeneration burning after timber harvesting than those in the litter (Vlug & Borden 1973). The importance of refuges such as those under logs and stones to species survival in burnt areas has also been demonstrated (Madden *et al.* 1976). The interior of decaying logs may offer another such refuge. This may explain why the log-dwelling fauna of older regrowth and old growth are similar (Taylor 1990).

Plantation development in native forests will most likely lead to the local extinction of *L. menalcas* populations, due to the virtual elimination of rotting logs. Populations may survive in the short term in windrows (Bashford 1990). However, by the second rotation most of this resource has rotted away, with little to no replacement of the log resource from standing timber. Specific prescriptions for the sustainable management of the rotting-log resource are likely to be required where large areas of native forest are converted to plantation, in order to limit the impact of such practices on *L. menalcas* and other organisms associated with decaying logs.

Conservation Status

Lissotes menalcas is presently classified as vulnerable under the Tasmanian *Threatened Species Protection Act* 1995. The Tasmanian Threatened Species Advisory Committee has released criteria for use in assessing the conservation status of species (Threatened Species Advisory Committee 1998). These are similar to those adopted by the IUCN except that Tasmania uses an additional category, rare. If these criteria are applied to the current situation, the species does not warrant listing as endangered or vulnerable but does qualify as rare, because of the size of its range (less than 100 x 100 km) combined with the fact that threatening processes (plantation development and clearing of forest on private land) are operating. Some of the criteria for assessing conservation status relate to the predicted extent of loss of habitat over the next ten years. If a species will undergo a population decline of at least 20% within the next ten years, it is considered to be vulnerable. Forestry Tasmania has adopted a policy of increasing its rate of plantation establishment on State forest to compensate for the loss of resource following tenure changes under the Tasmanian Regional Forest Agreement. Current planning estimates from Forestry Tasmania indicate that less than 10% of wet

eucalypt forest within the area of occurrence or within the predicted range will be converted to plantations over the next ten years. There is no indication of the future extent of loss of habitat on private land. However, the figure in Kirkpatrick (1991) indicates that clearing within the range of *L. menalcas* in the period 1980–88 was way below levels necessary to achieve a 20% reduction in *L. menalcas* habitat within the next ten years. It is recommended, therefore, that the status of the species under the Tasmanian *Threatened Species Protection Act* 1995 be changed from vulnerable to rare. However, given the restricted range of *L. menalcas*, monitoring of the impact of clearing and modification of habitat on the species should continue. This is particularly the case for private land where, unlike the situation on Crown land, no formal overview is being conducted. There is also a need to determine the effect of longer term ecological sustainability of native forest logging on the decaying log habitat. It is not known at present whether such habitat will be maintained after successive rotations of logging of native forest. Further assessment is also required of the effects of thinning of regrowth, a method increasingly being used to boost sawlog production from native forests.

ACKNOWLEDGEMENTS

This study was funded by the Australian Heritage Commission, the Forest Practices Board and Forestry Tasmania. Mark Wapstra, Daniel Vickers, Sarah Crute and Scott Barnes assisted with fieldwork. Collection records were provided by Mike Bouffard, Bob Mesibov, George Bornemissza, David Cowie, Andrew Vanderschoor and Dick Bashford. George Bornemissza and Andrew Vanderschoor also advised on sampling and provided information on the natural history of the species. The GIS section of the Parks and Wildlife Service ran the CORTEX modelling. Forestry Tasmania staff from Huon and Derwent Forestry districts assisted with access to and selection of sites. Data for table 1 was provided by Marco Giana and Luke Ellis of Forestry Tasmania. Bill Brown provided the photo of *L. menalcas*. Sarah Munks commented on a previous draft of this paper.

REFERENCES

ANDERSSON, L.I. & HYTTEBORN, H., 1991: Bryophytes and decaying wood — a comparison between managed and natural forest. *Holarct. Ecol.* 14: 121–130.

BADER, P., JANSSON, S. & JONSSON, B.G., 1995: Wood-inhabitating fungi and substratum decline in selectively logged boreal spruce forests. *Biol. Conserv.* 72: 355–362.

BASHFORD, D., 1990: The dispersal of ground beetles into different aged eucalypt plantations in north eastern Tasmania. *Tasforests* 2: 43–51.

BUSBY, J.R., 1991: BIOCLIM — A bioclimate analysis and prediction system. *In* Margules, C.R. & Austin, M.P. (Eds): *NATURE CONSERVATION: COST EFFECTIVE BIOLOGICAL SURVEYS AND DATA ANALYSIS.* CSIRO, Melbourne: 64–68.

GORE, J.A. & PATTERSON, W.A., 1986: Mass of downed wood in northern hardwood forests in New Hampshire: potential effects of forest management. *Can. J. For. Res.* 16: 335-339.

HARMON, M.E., FRANKLIN, J.F., SWANSON, F.J., SOLLINS, P., GREGORY, S.V., LATTIN, J.D., ANDERSON, N.H., CLINE, S.P., AUMEN, N.G., SEDELL, J.R., LIENKAEMPER, G.W., CROMACK, K., JR & CUMMINS, K.W., 1986: Ecology of coarse woody debris in temperate ecosystems. *Adv. Ecol. Res.* 15: 133–302.

JACKSON, J. & TAYLOR, R., 1994: *THREATENED FAUNA MANUAL FOR PRODUCTION FORESTS IN TASMANIA.* Forestry Tasmania, Hobart.

KIRKPATRICK, J., 1991: The magnitude and significance of land clearance in Tasmania in the 1980s. *Tasforests* 3: 11–14.

LEA, A.M., 1910: Notes on the genus *Lissotes*, with descriptions of new species. *Pap. Proc. R. Soc. Tasm.* 1910: 346–366.

MADDEN, J.L., HICKMAN, J.L., RICHARDSON, A.M.M. & HILL, L., 1976: Effect of cutting and regeneration practice on the invertebrate fauna of litter and soil. *WOODCHIP SYMPOSIUM PAPERS, 47th ANZAAS CONGRESS.* Tasmanian Forestry Commission, Hobart.

MEGGS, J.M., 1996: *PILOT STUDY OF THE EFFECTS OF MODERN LOGGING PRACTICES ON THE DECAYING-LOG HABITAT IN WET EUCALYPT FOREST IN SOUTH-EAST TASMANIA. Regional Forest Agreement — Tasmania.* Forestry Tasmania, Hobart: 75 pp.

MEGGS, J.M., 1999: Surveys for *Lissostes latidens* (broad-toothed stag beetle) in priority coupes on the Forestier and Tasman Peninsulas. Unpubl. rep. For. Tasm., Hobart: 10 pp.

MESIBOV, R., 1988: *Tasmanian Onychophora.* Unpubl. rep. Dep. Lands, Parks Wildl., Hobart: 44 pp.

MICHAELS, K., 1996: The occurrence of the endangered stag beetle *Lissostes latidens* (Westwood) (Coleoptera: Lucanidae) in selected areas in the Wielangta Forest Block, Tasmania. Unpubl. rep. For. Tasm., Hobart: 7 pp.

PETERS, D. & THACKWAY, R., 1998: *A NEW BIOGEOGRAPHIC REGIONALISATION FOR TASMANIA.* Rep. Nat. Heritage Trust, Tasm. Parks Wildl. Serv., Hobart.

STOCKWELL, D.R.B., 1993: A computational and theoretical basis for fauna modelling. Unpubl. rep. Tasm. Parks Wildl. Serv., Hobart.

TAYLOR, R.J., 1990: Occurrence of log-dwelling invertebrates in regeneration and oldgrowth wet sclerophyll forest in southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 124: 27–34.

THREATENED SPECIES ADVISORY COMMITTEE, 1998: *GUIDELINES FOR THE LISTING OF SPECIES UNDER THE TASMANIAN THREATENED SPECIES PROTECTION ACT 1995.* Department of Environment and Land Management, Hobart.

VLUG, H. & BORDEN, J.H., 1973: Soil Acari and Collembola populations affected by logging and slash burning in a coastal British Columbia coniferous forest. *Environ. Entomol.* 2: 1016-1023.

WESTWOOD, J.O., 1855: Descriptions of some new species of exotic Lucanidae. *Trans. Entomol. Soc. Lond.* 3: 197–221.

(accepted 29 March 1999)

CHARLES DARWIN'S FIELD NOTES ON THE GEOLOGY OF HOBART TOWN — A MODERN APPRAISAL

by Maxwell R. Banks and David Leaman

(with six text-figures and three plates)

BANKS, M.R., & LEAMAN, D.E., 1999 (31:x): Charles Darwin's field notes on the geology of Hobart Town — a modern appraisal. *Pap. Proc. R. Soc. Tasm.* 133(1): 29–50. ISSN 0080–4703. University of Tasmania and 38 View Street, Sandy Bay, Tasmania, Australia 7005 (MRB); Leaman Geophysics, GPO Box 320C, Hobart, Tasmania, Australia 7001 (DL).

A transcription of unpublished field notes made by Charles Darwin details the observations and initial deductions he made on the geology of Hobart, Tasmania, and comments thereon place his work in a modern context. The field notes enable the routes of his excursions while in Hobart Town to be inferred in considerable detail and confirm earlier ideas about the site from which important fossils were collected. They also allow some appreciation of Darwin's style of geological study.

Darwin's field notes reveal that he thought of the possibility of the influence of earthquakes on Tertiary beds at Sandy Bay. Several of his ideas on the geology, shown by these notes, some of them also in his publications (e.g. the origin of a Tertiary freshwater limestone, and relative movement of the land and sea in the area), remain topics for further study.

His work in the Hobart area and his understanding of the geology of Van Diemen's Land were enhanced by contact with George Frankland, Surveyor-General, who had a long-term and systematic interest in the topic.

The notes formed the basis of a geological "Memo on Hobart Town" and, later, two publications, each work having a different purpose and emphasis. His work near Hobart did not produce enough information for the construction of a stratigraphic framework ("imperfect sketches of the Geology"). The imperfections, with other considerations, may have influenced him not to publish the memo which rendered subsequent publications less clear and less useful than had the memo been published. Darwin recognised the influence of glaciation on the Permian sedimentary rocks in the area but did not publish his observations and interpretation.

Key Words: Charles Darwin, Hobart, Tasmania, geology, Frankland, Permian glaciation, Tertiary limestone, sea-level changes.

INTRODUCTION

Within three years of the return of HMS *Beagle* to England in 1836, Charles Darwin published a journal of his part in the voyage, a *Journal and Remarks* (Darwin 1839a – as Fitzroy 1839, Vol. III) and shortly thereafter separately as *Journal of Researches* ... (Darwin 1839b, 1845 and subsequently; the cover and spine bearing the words "*A naturalist's voyage round the World*", the title page, the words "*Journal of Researches etc. ...*"). This volume gave only a general account; the specialist aspects of Darwin's activities, e.g. geological and zoological, were published separately (for details see Nicholas & Nicholas 1989). The main vehicle of publication of his Australian geological observations and deductions was his *Geological Observations on the Volcanic Islands* (1844). The *Journal*... and *Geological Observations*... went through many editions and were subject to minor changes with time (Nicholas & Nicholas 1989: *X* and appendix 2).

Darwin visited Hobart Town early in February 1836, the town being one of the ports of call of HMS *Beagle* in its circumnavigation of the world under Captain FitzRoy. During an attempt 30 years ago to determine as accurately as possible the sites in the Hobart area from which Darwin had collected fossils, it was found that there existed in the University of Cambridge Library an unpublished "Memo on Hobart Town" by Darwin, which dealt largely with the geology of Hobart Town. This, made available by the Syndics of the University, revealed much more of Darwin's activities in and around Hobart than any published source and allowed the fossil sites to be identified, along with many of the places visited in his "pleasant little excursions" (Darwin 1839: 534) and, to some extent, when the excursions were made. The memo and a commentary thereon were published by Banks (1971). Subsequently, research by F. and J. Nicholas on Darwin's activities in Australia, enabled them to add a diary of Darwin's time in Hobart and to provide some details of his zoological observations (Nicholas & Nicholas 1989). They also made available to one of the authors (MRB) a microfilm of Darwin's field notes (DAR 40) and a transcription of them prepared by Mrs Jan Nicholas. This was subsequently refined somewhat by M.R. and D.M. Banks, particularly with respect to geological terms and phrases, so that most ambiguities are now removed.

With the field notes in hand, it became clear that some of the deductions made earlier about the routes were incorrect and that some parts of Darwin's routes had not been covered in the memo. Some interesting differences between his field notes and the memo will be considered later.

The aim of this paper is to publish, as far as possible, Darwin's field notes on the Hobart area, to interpret his observations in a modern context, to reconstruct more accurately than previously his "excursions" (figs 1–6), to consider the mode of Darwin's geological work in the area and to examine and possibly explain differences between his field notes , the memo, his *Journal of Researches* ... and his *Geological Observations on Volcanic Islands* ... with respect to the geology of Hobart Town. In attempting to achieve these aims, several problems raised by his observations were seen to be still unsolved, and attention is drawn to these.

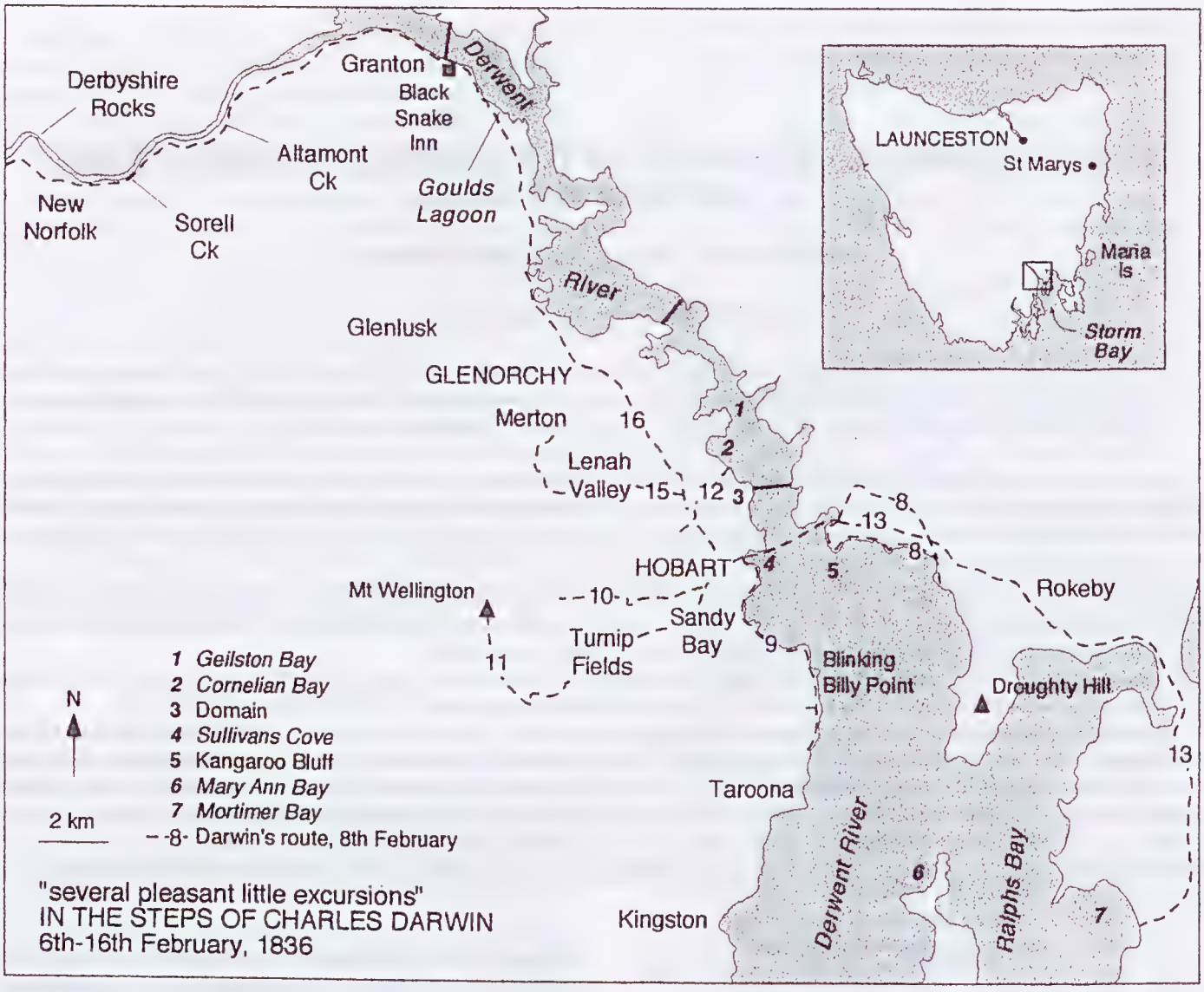


FIG. 1 — A map of the Hobart region showing the areas visited by Darwin.

THE FIELD NOTES AND COMMENTARY THEREON

The field notes printed below are those transcribed from the Geological Field Notes in the Darwin Archive, Cambridge University Library, DAR 40 Hobart Geology (pl. 1), by J. Nicholas, with amendments by M.R. and D.M. Banks. The page numbers used here, e.g. *(1)* , are transcribed from a copy of the microfilm and may not be part of Darwin's original text. They are, however, retained and used for the convenience of the reader. Darwin's text is rendered in italic font, textual comments by the present authors thereon are given in plain text in square brackets. Particular points in Darwin's notes on which we provide a commentary, mostly geological, are indicated by use of the page number and a reference letter. Material from Darwin's field notes quoted in the body of our text is rendered in italics.

(1

Feb 7th - In the town: Sandstones & Greenstones alternately appear, & perhaps in equal proportion — the Strata of Sandstone inclined, — In entrance of Harbour observed, a SW dip, not great.—Sandstone generally fine grained, particles of quartz with very little cement, — much fine grained laminated, & mottled pale red — alternate, [*sandy* inserted above] *clay Shale — There are many layers of very thin black carbonaceous matter & some Carbonaceous Shale.— Some Sandstone ferruginous I am doubtful whether stratification generally = -tal; on account of current cleavage:* 1A

Very general resemblance to Sydney — Here Trappean rocks far prevalent, — Basaltic Plateaus columnar — near mouth of Harbour. — 1B

Greenstone, generally well character[ised?] — coarse grained — even containing large Crysts of Hornblende — in Government domain — 1C

a [*Granitic* deleted] *Syenitic Greenstone — Only found one plane of contact, when* [or *where*] *some sandy shale & ferruginous* [inserted] *sandstone were in close proximity to a decomposing Greenstone — The strata were highly inclined & dipped from the mass at <* [angle sign] 1D

(See figure 2 for some details of localities near the Town.)

1E

1F

Commentary

1A: The *entrance of Harbour* probably refers to the entrance to the Derwent River. Sedimentary rocks at and to the north of Cape Direction, at the mouth of the Derwent (fig.1), dip at a low angle to the southwest, and this situation could be seen from a vessel moving up Storm Bay and the river.

1B: = *-tal* is a short form of "horizontal". Darwin used the

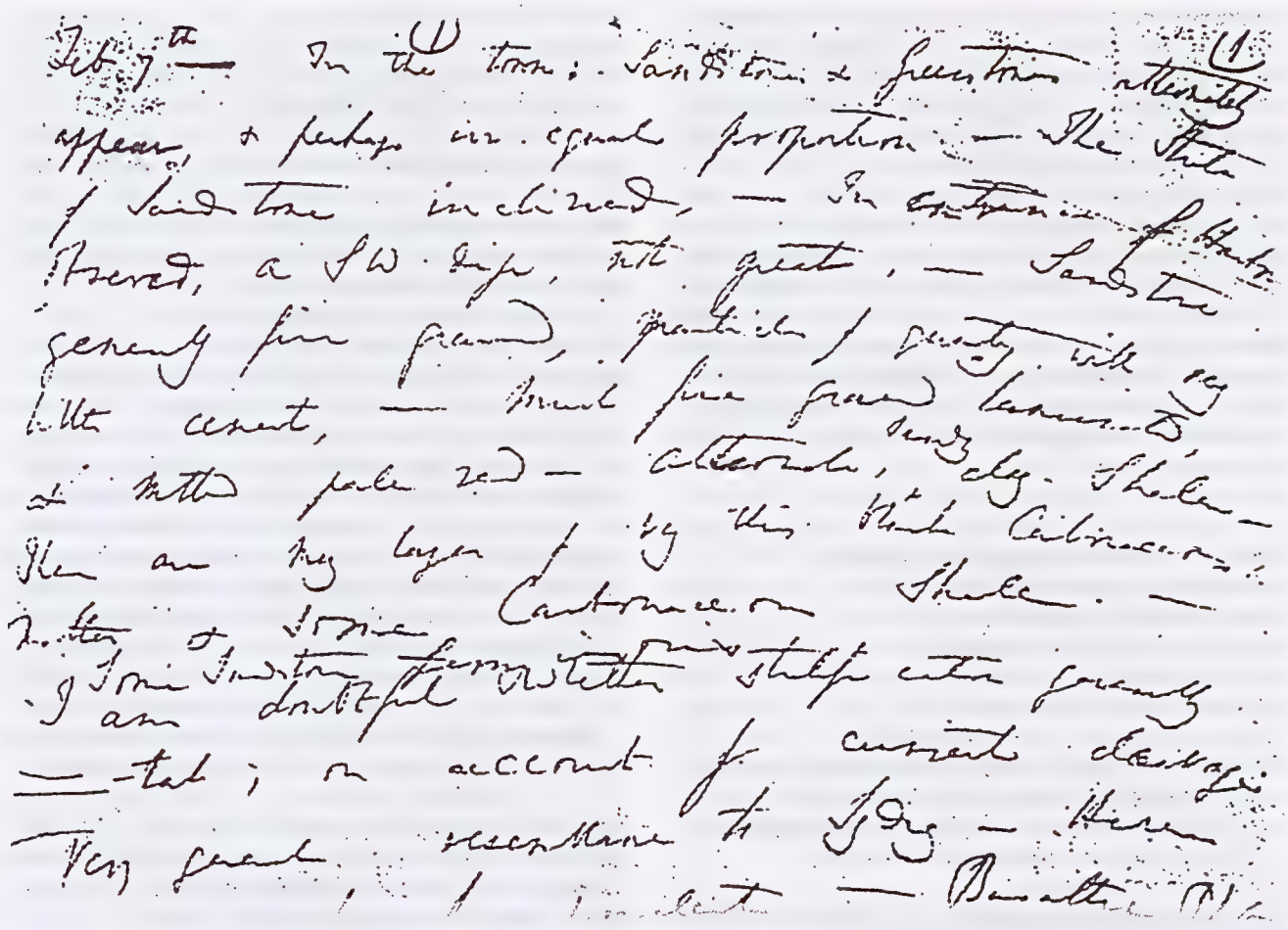


PLATE 1
Part of the first page of Darwin's field notes at about 5/6 original size.

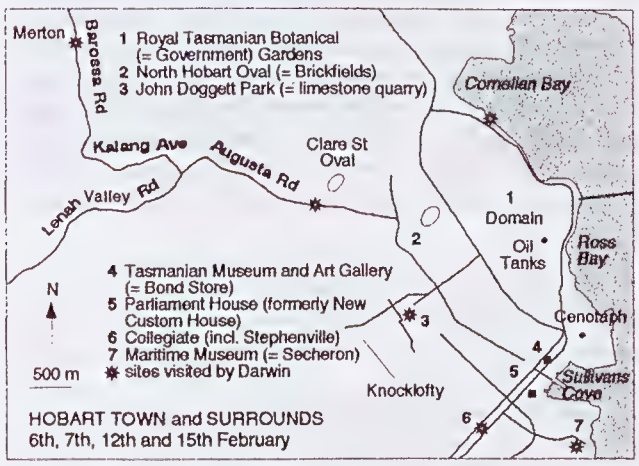


FIG. 2 — A map of the Hobart and Glenorchy areas, showing the areas visited by Darwin on 7, 12 and 15 February 1836.

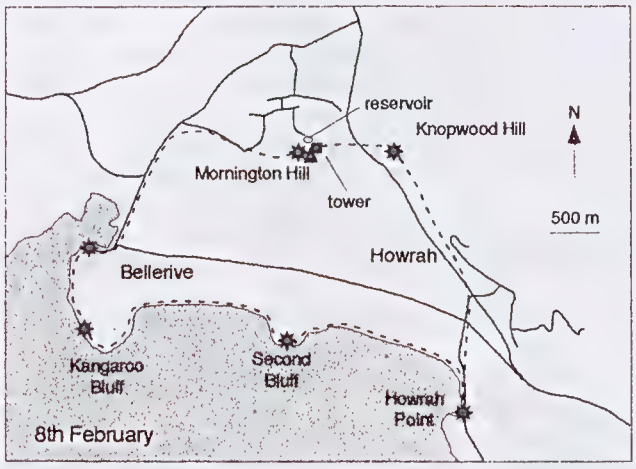


FIG. 3 — A map of the eastern shore of the Derwent showing the areas visited by Darwin on 8 February 1836.

term *current cleavage* in reference to what is now called cross-bedding.

1C: The sandstones Darwin saw in the neighbourhood of the town do indeed resemble the Hawkesbury Sandstone, so prominent around Sydney.

1D: Columnar jointing in the dolerite (*Basaltic Plateau*) is a prominent feature seen from a ship near the *mouth of Harbour* (i.e. Storm Bay): e.g. Tasman Island, Cape Pillar, Cape Raoul on the eastern shore and, on the western shore, Fluted Cape and Cape Queen Elizabeth. Darwin noted on p. 5 of his memo (Banks 1971: 7) that near Port Arthur he saw white horizontal strata faulted against greenstone (dolerite) and capped by greenstone. The site may have been close to Haines Bluff, at Cape Raoul, or in the small embayment west of Tunnel Bay.

1E: In these field notes and in his memo, Darwin referred consistently (except for a note on the back of p. 21 — Banks 1971: 13) and incorrectly, to the dark minerals (pyroxenes)

in the dolerite as *Hornblende.* The exception was a reference to hypersthene, an orthopyroxene; which does occur in the dolerite (Hergt & McDougall 1989: 378). Dolerite in the Domain approaches a granophyre in composition and texture and, in the state of knowledge at the time, could appropriately have been called *syenitic Greenstone.*

1F: This is the nonconformable contact of Tertiary claystone and ferruginous sandstone on the ancient landscape of weathered coarse-grained dolerite (*a decomposing Greenstone*) exposed on the shoreline for about 300 m southeast of Cornelian Bay Beach (fig. 2), the area referred to as "Pipeclay Bluff" by Johnston (1882). The Tertiary beds dip at up to more than 20° towards the river (Johnston 1882: fig. 4 [1]). Some beds of sandstone are cross-bedded. One lamina in a cross-bedded or slumped unit can be observed dipping at 58° towards the river.

2)
of 68 or 70 — The Shale, judging from fragments
altered into a Porcelain rock & the Sandstone 2A
rendered much harder & compact. —
Thus origin of some of the Trappean rock
explained = Conical hills over whole country 2B
Fossil shells in district of Launceston.— 2C

Walking Coast to South on E side of ferry; Greenstones; then 2D
in close neighbourhood, a quite white — pottery-like
very fine grained Sandstone, — in parts rather more Sandy
in others frequently more Aluminous or porcelain like
((3447:48) Vide description
is crossed by many veins ferruginous, which project upwards 2E
passes into & overlies a blueish rock, possessing more
of the character of Clay Slate. — These two contain
few impressions of Terebratula & a very few rounded
pebbles of Quartz rock — Siliceous stones, like what will
be described & one volcanic looking pebble.— 2F
Strata dip at small < [angle sign] *Easterly. — I believe*
but am not sure, this is coeval with General 2G
Sandstone. — (N B observed flat at high
water line, I remember it is same at Chiloe & Port 2H
Famine) [*New Zealand* inserted].— *There appears to have*
been a
general rise —Shells on sides in beds in very many
parts — get deep water in Coves; & similarity of productions 2I

(See figure 3 for localities on the *#E side of the ferry.*)

Commentary

2A: The shale and sandstone are hardened in some places by cementation by calcium carbonate or, in others, by silica derived from the decomposition of the dolerite.

2B: Darwin may have been told of the *conical hills* by Frankland; such hills (possibly assumed by Darwin to be volcanoes) are to be found particularly in the Midlands of Tasmania; some are capped by basalt, most by dolerite.

2C: The reference to the *Fossil shells in district of Launceston* must be based on information Darwin had received from George Frankland, the Surveyor-General of Van Diemen's Land (VDL) at the time of Darwin's visit (see below for more detail). This inference suggests that Darwin met Frankland within a day or so of the arrival of the *Beagle* as these comments precede his notes on his walk on the eastern shore on Monday, 8 February.

2D: In walking west along the foreshore from the ferry wharf, Darwin walked from dolerite over a contact onto the overlying Fern Tree Mudstone. The mudstone above the dolerite sheet has been contact metamorphosed. To the south, the broad shelves of the rock are blanched white by modern weathering processes, and some have a porcellanous appearance. Some beds are sandy. Local stratigraphic names (e.g. Fern Tree Mudstone) were not applied to rock units in the Hobart area until the 20th century. The relationships of local rock units named in this text are dealt with by Banks & Hale (1958) and Leaman (1976).

"*3447:48*" are specimen numbers.

2E: *ferruginous* joint fillings are common in the Fern Tree Mudstone along the foreshore, particularly close to Bellerive Bluff. Many resist erosion and form ridges. The *blueish* colour noted by Darwin is normal in the fresh mudstone.

2F: *volcanic looking pebble,* a dropstone in the Fern Tree Mudstone, may have been a Cambrian volcanic rock such as occurs now in western Tasmania, a Devonian volcanic rock originally from the St Marys area in northeastern Tasmania or a fine- to medium-grained intrusive rock such as occurs widely in northeastern and western Tasmania. Pebbles of other compositions (especially siliceous) are more common. The fossils (brachiopods) are rare and restricted to one or two beds only (the sites are shown by Leaman 1972).

Note that, on the following line, Darwin attributed an easterly dip to the mudstone. It has, in fact, a westerly dip of 1° to 3° overall.

2G: The Fern Tree Mudstone Darwin saw on the shore platform at Bellerive is Permian, the *General Sandstone* is Triassic, i.e. they are not, as he supposed, *coeval.* " Permian" and "Triassic" were not terms used by Darwin.

2H: Darwin correctly observed that there is a relatively flat zone at and just above high-water mark, a feature common in shore platforms developed in Permian sedimentary rocks in southeastern Tasmania. Port Famine is in Tierra del Fuego.

2I: Many of the embayments along the shores of the Derwent River are deep e.g. Sullivans Cove (see also comment 3A). It may be that, as Darwin walked around the shore near Kangaroo Bluff, he looked across the river, noted ships anchored in Sullivans Cove and realised that there was deep water close to the shore, not a feature of every port. It is likely that the *productions* referred to the marine flora and fauna.

between here & Australia, & soundings in *(3*
channel as if Subsidence. — 3A
Water is said to be retiring. — Earthquakes?

Beyond these white beds we find ordinary
Sandstones with current cleavage & then 3B
again appears The greenstone — 3C

Ascending the hills, some hundred ft
behind the coast, we met with common
Greenstone but the commonest rock
is a Greenstone [above this (*3453*)] *—Syenite — On the* 3D
summit there were gently inclined Strata
of altered rocks —Siliceous white, & 3E
blue — Siliceo-porcelain rocks 3F
(3449: 3450)
& 3451 — Greenstone (?) poss. belonging to the
axis of the hill? [last nine words encircled] 3G
I must believe from these came the
pebbles in the lower beds; otherwise 3H
I should think the same only slightly

Commentary

3A: The deep water noted earlier may indicate subsidence (presumably due to tectonic causes), as suggested by Darwin, or, at least in part (as later work has suggested), rise in sea level.

3B: The *Sandstones with current cleavage* outcrop in fine sections at Second Bluff.

3C: *The greenstone* outcrops on the shoreline at Howrah. At this point Darwin seems to have turned inland, possibly because of the state of the tide, possibly to ensure that he reached the ferry in time for a return trip. "Predicted" high tide was at about 12.30 p.m. The trip across in the morning was probably enjoyable, as the air temperature at 9 a.m. was about 13°C with a light, variable breeze (FitzRoy, *Narrative*, appendix to Volume II: 51–52). It should, perhaps, be noted that Darwin not only looked at the geology but also at animals and plants. He is known to have collected shoreline animals as well as rocks.

3D: Granophyre occurs on Knopwood Hill NNE of Howrah and could well have been called *Syenite* by Darwin. He probably traversed the western slope of the spur leading to Knopwood Hill.

3E: The *gently inclined strata* belong to the Fern Tree Mudstone and outcrop on Knopwood Hill.

3F: On the southwest flank of Knopwood Hill the grade of contact metamorphism of the Fern Tree Mudstone is relatively high; the rock looks porcellanous.

3G: Near the summit of Knopwood Hill, dolerite forms the axis of the hill and is thought to be part of a feeder. There are irregular plug-like outcrops of dolerite. The western spur of the Hill is capped by siltstone and the contact between dolerite and siltstone is now visible on the northern slope of the hill in the face of Mornington Quarry.

3H: It seems that the *volcanic looking pebbles* (see Comment 2F) looked like the dolerite on parts of Knopwood Hill which Darwin would have traversed on his way back to the ferry via Mornington Hill (see Comment 4A); this suggests that the pebbles seen by Darwin were intermediate or mafic plutonic rocks. The *greenstone* at the *axis of the hill* is Jurassic dolerite and could not have been the source of the pebbles in the Permian mudstone.

4)

Metamorphised [sic].— *On a neighbouring & higher hill, whole rock a dull red ordinary Sandstone — Do the hard rocks belong to a distinct formation?* 4A

Tuesday 10th [*sic:* should be *9th*.] *Walked coast South of town. — Greenstones; generally globular concentric structure:* 4B *in close connection with inclined strata, (but not inclined by this rock) of Sandstone Conglomerate,* 4C *containing numerous pebbles of the underlying GreenStone; the White Chert with Organic impressions &c &c:* 4D [*Alternately* deleted] *covered with softish Sandstones; which however in parts, are firmer & whiter* 4E *& are quarried — associated with layers of slightly indurated Clayey beds & other ferruginous ones: — perhaps inclination from original* 4F *deposition: — Many of the white pebbles strictly resemble the* [*Porcelain* inserted] *beds of yesterday: —* 4G *Still travelling onwards, preponderant quantity*

(See figure 4 for route *South of Town*.)

Commentary

4A: As Darwin walked from Knopwood Hill back towards the ferry he could well have seen red siltstone in the saddle between Knopwood Hill and Mornington Hill, on the higher slopes and top of which *dull red ... sandstone* is common. The colour is well displayed in a quarry now cut in these slopes. The observations, revealed in the field notes (i.e. on Second Bluff, Howrah, Knopwood Hill and Mornington Hill), make it clear that the route up Flagstaff Hill, as interpreted by Banks (1971: 10) from the memo, was incorrect.

4B: the *globular concentric structure* is onion-skin (spheroidal) weathering in the dolerite that outcrops along the shoreline around Battery Point.

4C: The rocks described here outcrop in low cliffs behind what is now Marieville Esplanade, but now are largely concealed by vegetation and buildings. Darwin correctly considered them not to have been tilted by the greenstone.

4D: *White Chert with Organic impressions* which *strictly resemble the ... beds of yesterday* (4G) may have been pieces of Fern Tree Mudstone with trace fossils (fossil burrows and faecal pellets), as seen by Darwin on the Bellerive foreshore, derived from outcrops, now eroded, from above the dolerite on Battery Point or from the upthrown block of the fault cutting the University site just above Churchill Avenue. Had Darwin seen fossil shells or fossil plants it is likely that he would have used those terms rather than the general term *organic impressions*. (See Comments 7 F, G, and H.)

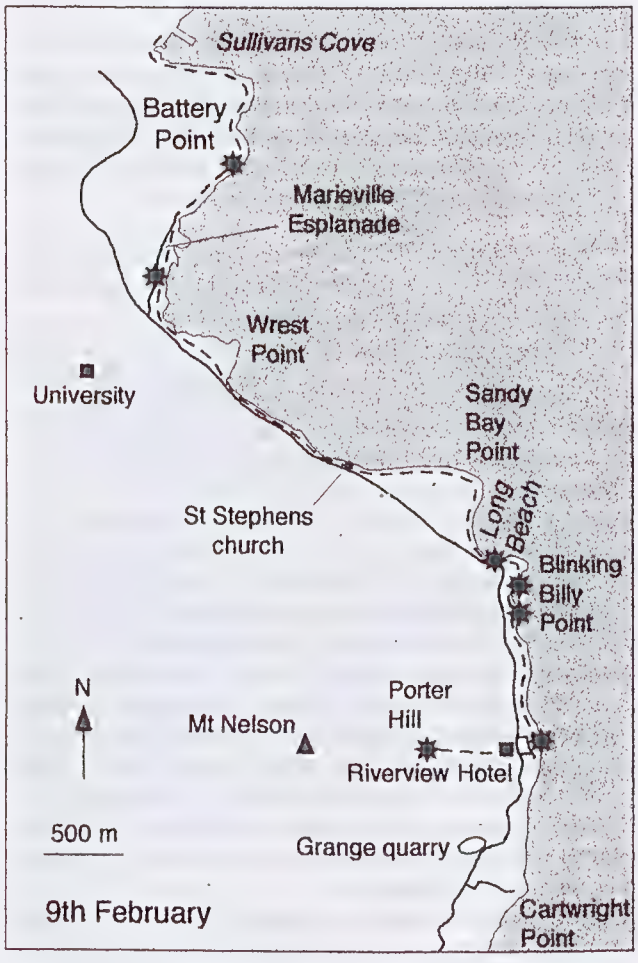


FIG. 4 — A map of the western shore showing the areas visited by Darwin on 9 February 1836.

4E: The *softish Sandstones ... quarried* are likely to have been Tertiary, though we know of no record of their having been quarried.
4F: The inclination of the clayey beds, as noted by Darwin, was shown by Johnston (1882) as due to faulting, the fault being close to the southwestern end of the cliffs behind Marieville Esplanade.
4G: Probably Fern Tree Mudstone (see Comment 4D) but may have been Tertiary.

of Greenstone [two words deleted] *generally, what I (5* 5A
call Syenitic like 3453) [*like 3453* encircled]. — *We then meet* 5B
with some white softened, rather thinly stratified
mass of Aluminous Sandstone: (Somewhat
like those of Chiloe) which rested on a
Sandstone : & it contained some darkish 5C
impure clayey beds — on these rested
a stratum of compact (few minute [underlined twice]
vesicular cavities) 3467 [number encircled] *blackish Basalt,*
containing
numerous atoms of red Olivine.— 5D
(NB in the white beds, there was one
stratum brecciated with pieces of same 5E
kind with itself: would not these cases
be produced by violent Earthquake beneath
the spot at time of deposition.)
This basalt had a greenish tinge
externally: it was separated from a
superior stratum of similar kind, by

Commentary

5A: The *greenstone* was probably seen at Wrest Point and along the shore south to Manning Avenue, where large blocks of dolerite outcrop on the shoreline. Darwin did not realise (probably could not have realised) that the blocks are not bedrock but large boulders derived from the dolerite on Mt Nelson by a rock slide or slides (Stevenson 1971: 115-117).
5B: It is surprising that Darwin made no clear mention of the sandstone (Triassic) in low cliffs along the shoreline at Red Chapel Ave, which dips north at about 30°.
5C: The *white, softened, thinly stratified ... aluminous sandstone* probably refers to Tertiary beds like those now exposed in the cuttings on the Channel Highway at Long Beach (Banks 1971: 6), but cuttings are unlikely to have been present early in 1836. Work on upgrading the pre-existing cart track to a road started in August 1835 (Lord 1998: 9). However, reference to the drawing of this exposure in Johnston (1882: fig.1) and consideration of the topography, suggests the possibility of outcrops in low cliffs behind the shore, which Darwin could have seen. The identity of the *Sandstone* on which this sequence is said to rest is not clear; it may have been (a) the Triassic sandstone in the cliffs under St Stephens Church, though this outcrop is distant from any present outcrop of the Tertiary rocks, (b) the Permian sandstone and mudstone exposed in the cutting beside Sandy Bay Road between Mt St Canice and Fisher Avenues. Johnston (1882) showed Tertiary beds resting against and on the rocks near Fisher Avenue. The contact was still visible 50 years ago.
5D: The *Basalt* (Tertiary) was described in detail by Spry (1955) and shown to be about 26 million years old by Sutherland & Wellman (1986: 84).
5E: *brecciated with pieces of the same.* Some of the beds in the outcrop contain angular blocks of white mudstones up to 20 mm long, some friable, some compact. Darwin suggested an origin involving disturbance of a slope underlain by mudstone by tremors associated with earthquakes. He did not remark on the boulder beds at the base of the Tertiary sequence here, as revealed by more recent road cuttings, the boulders being of Permian mudstone (Johnston 1882). Johnston regarded these beds as resulting from cliff collapse due to wave undercutting of cliffs of the Permian siltstone (his "Porter Hill Beds" which crop out just to the north). In 1947, Professor S.W. Carey explained such occurrences to Geology I students in Darwin's terms, but such an origin was not published until 1955 (Spry 1955).

6) (3469)
angular bed of Wacke or vesicular Clay 6A
or Tufa for it wore all these appearances
it contained balls and masses of true Basalt.
I found by tracing structure it is decomposed
scoria, clearly separating two streams : These
& the lower Sandstone beds all dipped S
at angle of about 30°. — following for a few
100 yards the Basaltic beach, came to
cliffs entirely composed of cemented fragments, 6B
very vesicular, & possess vesicular cavities
linear following sweeping lines, lined with
green matter (3468).— Amidst fragments [word off page?]
of red jaspery & Porcelain rock. — This flat 6C
point, now formed of such confused, vesicular
rocks probably old Crater, now no trace of
do — This is the first of the great 6D
Basaltic columnar streams which we saw
at the mouth.— Directly beyond this
point, & near, we again had, the Greenstone

Commentary

6A: *Wacke* was probably used by Darwin here in the sense of Lyell (1830) — i.e. "a rock nearly allied to basalt, of which it may be regarded as a soft and earthy variety"; *Tufa* was defined by Lyell as "a volcanic rock of earthy texture, seldom very compact, and composed of an agglutination of fragments of scoriae and loose matter ejected from a volcano". These definitions occur in the Glossary at the end of Volume 1 of Lyell's *Principles of Geology* (1830), which Darwin had on the *Beagle.*
6B: This description refers to breccias and scoria exposed in the cliffs at the southern end of the beach immediately south of Blinking Billy Point.
6C: The *red jaspery & Porcelain rock* probably refers to chalcedonic veins, noted by Spry (1955).
6D: The reasoning behind the statement *This ... at the mouth* (i.e. at the mouth of Storm Bay) is not clear, and the conclusion is incorrect — the crater and the lava associated with it are Tertiary, the *Basaltic columnar streams* are thick intrusive sheets of Jurassic dolerite. Darwin may have noted the similarity of the columns in the dolerite to the prismatic cooling columns in volcanic rocks well known to European observers at places such as Fingals Cave, Giants Causeway, Auvergne and on several Mediterranean islands, without appreciating the difference in scale (Leaman 1999). Lyell mentioned such columns under "Basalt" in his Glossary (1830) and figured them in a drawing of the Isle of Cyclops in Volume 3 (1833), which Darwin received while in South America.

its appearance externally is quite like that of (7
Granite — indeed I believe it is such, but 7A
imperfect (V [*Vide*?] *3455) — Beyond this we* 7B
have strata full of organic remains, which
will be described — Beyond this immediately
the Granite, which continues for some miles
along the Coast.— The organic beds appear 7C
here the lowest — The Volcano has burst 7D
through these. — It may be suspected this
Granite has been protruded subsequent to 7D
the Organic beds. = These latter consist of
gently inclined Strata of 3 varieties and their
intermediate variations — a white cherty rock
with grains of quartz. 7E
(3457) — a blue, slightly Calcareous, siliceous
Clay [inserted above – *not laminated*] *Slate* [erasure]
(3458) & a brown rather
softer do [ditto?] *(3459)— These two latter in places*
are softer and thinly laminated — all three
are composed of impressions of Betepora & other 7F
Coralline (Mem. Limestone of Argyl) & some few 7G
Terebratulae. I saw impressions of one Univalve & a large 7H
Bivalve —

Commentary

7A: The *granitic* appearance of the greenstone which is coarse-grained, is due to differential alteration of the minerals in the coarse-grained dolerite, as noted by Banks (1971: 10). In the memo, Darwin reported "mica" in the rock. He had noted, probably during shipboard examination of his specimen (3455), very shiny, dark crystal faces which he identified as mica, a common component of granite. The shiny faces probably belong to orthopyroxene showing schiller structure, a structure not recognised until 1885 (Judd 1885), which Darwin could not have detected with the equipment available to him in 1836.

7B: The fossiliferous beds (*strata full of organic remains*) outcrop over only 200 m of shore platform and fringing cliffs centred on a point 476N on the *TAROONA* 1: 25 000 Map Sheet. Fossils are abundant and beautifully preserved.

7C: The dolerite (*granite*) does not *continue for some miles along the coast.* It extends to Cartwright Creek, just over 0.8 km south of the outcrop of the fossiliferous beds. Darwin clearly did not walk as far as Cartwright Point, just beyond the creek mouth as, from there, he would have seen cliffs of bedded Tertiary sedimentary rocks and would hardly have failed to mention them. From the dolerite point immediately south of the fossiliferous beds, he may well have looked south along the coast or even walked as far south as the point immediately south of the mouth of Riverview Rivulet and then looked south. As far as he could have seen, the cliffs are dolerite. Just beyond this southerly point, there is a break in the shore platform which would have been well and truly awash at high tide and passable only with difficulty and discomfort. The tidal "predictions" provided by Dr Bill Mitchell, National Tidal Institute, Flinders University, Adelaide, indicate that the tide would have been high early in the afternoon (about 2 pm) and the meteorological record in the appendix to FitzRoy's *Narrative* ... (1839) shows a noon air temperature of 17°C and a fresh (i.e. >5 knot) southeasterly breeze (a sea breeze) blowing at noon, which would have made the passage more difficult and uncomfortable. It is possible that Darwin took advantage of the gap in the cliff-line provided by the mouth of Riverview Rivulet to leave the shoreline, whence he could have ascended the Rivulet to Porter Hill.

7D: Darwin expressed here the correct age relationship of the fossiliferous beds to the dolerite, i.e. the dolerite subsequent to the sedimentary rocks.

7E: The rocks present are calcareous mudstone with some beds of limestone, mudstone, some of which weathers brown, some white or almost so (the *white cherty rock*). The rocks are correlated with the Bundella Mudstone.

7F: *Betepora* should be *Retepora* (a bryozoan).

7G: The bracketed insertion seems to be a note that the fossils seen here reminded Darwin of the fossils in the Carboniferous limestones of Argyll, which he may have seen during excursions led by Professor Robert Jameson in connection with the Wernerian Society of Edinburgh (Desmond & Moore 1991: 42) or during his travels in Scotland after leaving Edinburgh in April 1827 (ibid.: 45). The Carboniferous limestones of Argyll occur near Machrihanish (Johnstone 1966: 70).

7H: *Terebratulae* was the term applied by Darwin to any of the several kinds of fossil brachiopods he saw near Hobart. Gasteropods (*Univalve*) and large *Bivalves*, of the genus *Eurydesma*, occur in the sedimentary rocks on the shoreline.

8)
Some of the Corallines, pretty silicified,— a [? @] 8A
most few pebbles of quartz, blue siliceous Sandstone 8B
& a glassy micaceous Clay Slate. — This is 8C
evidently same as Beds of Yesterday; there
are Specimens from near Launceston identical 8D
(3470 3471). — The neighbouring mountain, 8E
is in its lower parts thus constituted;
these beds are covered to the thickness
of some hundred feet, with rather siliceous
reddish, yellow, or white Sandstone, with granules
of quartz (3466), — There however at summit
[to the right of these lines a broad arrow >]
a pass of dubious Greenstone (3456) & lower
down another of Basalt. —
Thus we see, Retepora strata, with their
Sandstone, have been preceded judging by pebbles by 8F
Siliceous Sandstones, (which rocks perhaps were
those I yesterday examined) — have been
probably upheaved by the Syenitic Greenstones, otherwise
in such close proximity, there would have been pebbles. 8G
These two distinct formations have been

Commentary

8A: *silicified* bryozoans have not subsequently been reported from this site and recent close examination failed to disclose any. Within, but close to the landward edge of the rock platform washed by waves, the bryozoans, particularly the fenestellids, stand out from the general level of the outcrop, many of them pale in colour, and might be thought to be silicified. The fenestellids were referred to as *Retepora* by Darwin. They react with dilute hydrochloric acid, indicating the presence of calcium carbonate.

8B: Dark grey sandstone crops out close to the fault at the southern end of the exposure but *blue siliceous Sandstone* is likely to refer to pebbles of this nature, now regarded as dropstones derived from earlier Palaeozoic or Precambrian outcrops in western Tasmania.

8C: The *glassy micaceous Clay Slate* was probably a dropstone of Precambrian schist or of micaceous phyllite of early Palaeozoic age.

8D: It seems likely that Darwin had seen specimens in Frankland's collection.
8E: *The neighbouring mountain* is Porter Hill. The *Sandstone, with granules* is Member A of the Malbina Formation which outcrops on Porter Hill and is intruded by dolerite near the top of the hill, the dolerite being fine-grained (*Basalt*) at the contact and somewhat coarser at the summit, beyond which is a low saddle separating Porter Hill from the main mass of Mt Nelson.

This section of the field notes shows that Darwin climbed Porter Hill, an activity not hinted at in the memo or in his published works. The section also places any location other than the shoreline below Porter Hill out of contention as the site from which Darwin collected the type specimen of *Stenopora tasmaniensis* Lonsdale (cf. Banks 1971: 9).
8F: *pebbles* — dropstones of older rocks, including those of earlier Palaeozoic siliceous sandstone.
8G: Darwin correctly pointed out that, had the greenstone been older than the sandstone, pebbles of greenstone might have been expected in the sandstone.

succeeded by other Sandstones, Clays & Shales *(9*
which alternate with Lavas— & partly amongst
which most of the Freestone will be
classed [?] —Thus we have sandstone of
three distinct ages. — perhaps the most *9A*
modern in mere fringes. —

A good deal of Resemblance with
New Zealand & with Australia.

---

as in the Sandstone Conglomerate (most modern) there
[opposite broad arrow on p.8]
was white freestone, perhaps some such occurs in
parts of this series, & the Sandstone in the
town must remain of doubtful age.

NB. this most modern Sandstone was crossed by *9B*
ferruginous veins in nests, like older series

I found shells in such quantities 10–30 & 40
ft above high water all along fields [?]*; I am* *9C*
tempted to believe upheaval. — Comminuted, difficult
to decide [next five words inserted possibly in pencil]
not having visited wild parts.
Agriculture. — Parts in heaps —
Yet very much spread — [symbol here like "Z" with vertical
middle limb] *on small*
scale, few pebbles on upper surfaces. —

Commentary

9A: Darwin seems to have decided on the correct number of sandstones, i.e. three: one Permian (on Porter Hill), one Triassic (*in the town*), one Tertiary (*most modern*), but he was unable to assign the correct relative age to all outcrops of the older sandstones.
9B: *nests* — Darwin saw the *most modern sandstone* (*mere fringes*) at Cornelian Bay, Marieville Esplanade and Long Beach. In the gravels on the foreshore at Cornelian Bay, beneath cliffs of Tertiary sandstone, siltstone and claystone, ovoid bodies occur which have a structure like that of wasps' nests. in places the cavities in the *nests* can be seen to be partly filled with ferruginous clastic sediment. The cavities are delineated by "septa" of white and pink to reddish calcium carbonate. The bodies probably originated as septarian nodules in the Tertiary sediments. Darwin seems to have been likening the *nests* and possibly the network of ferruginous veins present in places, to the pattern of ferruginous veins seen in the Fern Tree Mudstone on 8 February.
9C: Darwin showed an inclination to accept the occurrence of shell beds 3–13 m above high water mark as due to uplift but was clearly uncertain. Beds within this range of heights extend considerable distances between Cornelian Bay and the Royal Tasmanian Botanical Gardens on the eastern slope of the "Government domain".

10)
Strata with impressions, half-Slate, Chert Sandstone 10A
— Limestone.— capped by Sandstone, reddish
[underlined beginning of word off page]
did not see Stratification: — up to perhaps
12-1400 ft — rest Greenstone of one character
Crystals of Hornblende — columnar — large 10B
flat surface — grand extensive formation 10C
many [*ditto* inserted] *mountains — enormous blocks, numer …* 10D

(See map, figure 5.)

Commentary

10A: This is a very brief description of the rocks seen during the ascent of Mt Wellington (fig. 5: Routes 10 and 11 February). In the discussion of the route in the paper on the memo (Banks 1971: Comment L, p. 7) mention was made of the possibility that he used the coach road, but this was not opened until 1869 (de Quincey 1987: 55). It is known from Darwin's diary that he climbed the southern side of the mountain. His most likely route would be to have followed the early part of the Bridle "Road" from Hobart Town to the Huon River, i.e. from Fitzroy Gardens or Stoney Steps along the valley of Wellington (now Sandy Bay) Rivulet to Halls Saddle close to the present junction of Chimney Pot Hill Road and the Huon Road. If he traversed the northern side of the valley, he would have travelled over the rock types noted (e.g. *strata with impressions, limestone* at Turnip Fields). Darwin's assistant, Syms Covington, described the route as "very intricate roads" (Covington 1831–36).

Darwin's description of this section is rather fuller (but more dispersed) in his memo.

We suspect that it was not a very good day to be climbing Mt Wellington. The 9 a.m. air temperature was already 19.5°C, there was a moderate (5 to 6 knot) NNW wind and the barometric pressure was 30.19 in. The day was *splendidly clear* (Darwin in his diary) — a typical early February day with an anticyclonic area over Tasmania, and probably with hot winds coming from the centre of Australia. Darwin also reported in his diary that it had taken $5^1/_2$ hours to reach the summit from the *Beagle*, which they did not reach on return until 8 pm *after a severe day's work.*
10B: It is clear from this comment that Darwin noted the columns in the *Greenstone*, so clear in the Organ Pipes, but did not comment on their being volcanic or otherwise.
10C: Darwin's comment on the *large flat surface* was expanded in the memo (Banks 1971:11).
10D: The *enormous blocks* are common and obvious in the scree (block fields) beneath the Organ Pipes and elsewhere on the Mountain; Darwin may well have climbed over the block fields during his ascent as they are less thickly vegetated than areas underlain by solid rock.

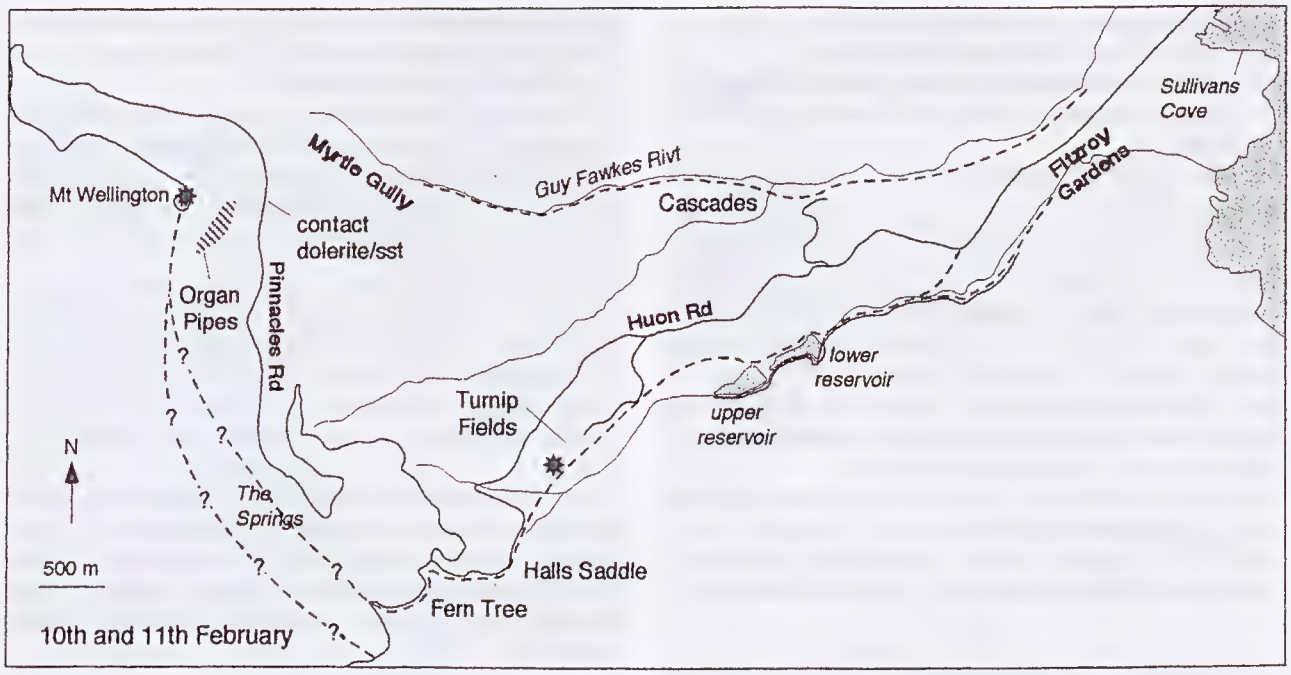


FIG. 5 — A map of the Hobart–Mt Wellington area showing possible routes on 10 and 11 February 1836.

X II

Friday 12th — limestone quarry — Stratified dip about 50° — occasional pebbles of quartzose rock — cellular linear cavities — pale brown — pure Limestone —
Layers of flint — very numerous impressions of leaves. Said to be different from present same — Whole hill covered by very curious 11A
formation, balls of Trappean rocks — decomposed, so as to resemble Wacke, Calcareous [Aluminous inserted above] 11B
matter (like St Jago) 11C
few pebbles — broad fissure in underlying rock & [or is] filled up — Volcanic Eruption somewhere near. subsequent to upheaval but beneath Water — Very limited formation — sm. creek [last two words encircled] 11D

Sandstone in Government domain, not Stratified 11E
very free — I certainly believe, the 3d formation. 11F
— Broken by Trap rocks: — There is a hard Siliceous Sandstone quarried high up, may belong to the older — 11G

Shells in the Government domain. 60 or 80 ft generally round pebbles — much to be said on both sides 30 or 40 — wonderful numerous [?] *— yet has not quite —Small Shells. — appearance of upraised beach —Certainly much shells brought by natives - pile stone hatchets — But these may have been upheaved: Bay formerly low land — Shells. beach — pebbles* [*of* deleted] *with Serpula* 11H 11I

(See figure 2 and plate 2 for the limestone quarry.)

Commentary

11A: The limestone quarry referred to here is the former quarry in West Hobart above Burnett Street (fig. 2) and within the block bounded by Arthur, Lochner, Hamilton and Brown Streets. It is referred to variously as " within the outskirts of Hobart Town" (M), "behind Hobart Town" (V), "Arthur Street quarry" (*Statistics of Van Diemen's Land*, 1842), "at Hobart Town" (Strzelecki 1845), "outskirts of Hobart Town" (Jukes 1847), "in the vicinity of Hobart" (M'Cormack, 1847), "in the suburbs of Hobart Town between Elizabeth Street and 'Knocklofty Range' " (Milligan 1849), "the neighbourhood of Burnet - street, Hobart" (Johnston 1882 and 1888) and "Shoebridge's Lime Kiln" by Ettingshausen 1883).

The quarry has been filled in and the site is now occupied by John Doggett Park. From the quarry came limestone deposited from a spring (Darwin 1844) and burnt in Shoobridge's Lime Kiln. A detailed consideration of this deposit may be found below (under "Challenges Disinterred").

11B: The *balls of Trappean rocks* are the fresh cores of weathered blocks of dolerite.

11C: For definition of wacke see Comment 6A.

PLATE 2

Photograph of the Burnett Street (Shoobridge's) Quarry looking south, taken by Charles A. Woolley in about 1861 (reproduced by courtesy of Mr Lewis Woolley). White areas within the quarry limits are probably travertine, the darker material, wacke. Note that the white mass near the northeastern corner of the quarry dips quite steeply in a southerly direction.

11D: The suggestion of volcanic activity close to the quarry is discussed below ("Challenges Disinterred").
11E: This sandstone may be Tertiary sandstone cropping out along the shoreline below the Domain just south of Cornelian Bay.
11F: *free* refers to the property of many of the sandstones of splitting readily.
11G: The sandstone being quarried *higher up* could refer to quarries in Triassic sandstone, subsequently the site of Beaumaris Zoo and the Oil Tanks, or to the quarries in the grounds of what is now Government House. The sandstone also crops out near the Powder Jetty in Ross Bay (273.532 on the *HOBART* 1:25 000 Map Sheet).
11H: This report of shells at 60–80 ft (18–24 m) in the Government Domain is fascinating.and is considered more fully below (see "Challenges Disinterred").
11I: It is not known where Darwin saw the pebbles encrusted with the tubes made by the marine worm *Serpula* (the worm was probably a serpulid, but not *Serpula*) (fig. 6). The matter is more fully discussed below (see "Challenges Disinterred").

Blue Limestone in old formation ***X 12*** 12A
12–15 ft above present high water — Before
However the low land had formed Harbor
considerable fetch — Yet [a symbol like a "Z" with a vertical middle limb] *& these facts inclined*
me to believe, — trifling rise — Mr F. — 12B
oysters have all disappeared within 2 years
Mem. Ascidia in Chiloe only known [?] *with*
edible animals — Earthquakes

Centre of Island lofty Greenstone — divided by valley
of the Derwent — On North side grand formation 12C
of Limestone & some Conglomerate, & [*hard* inserted]
Clay Slate [words or letters off page]
see fossils same formation — Limestones & Conglomerates
replacing beds Here.— Again on [*North* inserted] *Coast. Basaltic*
formation — Here the old formation probably extends
to Is [*Santa?* deleted] *Maria — Coal probably 3d*
formation — On the NE extensive Granite 12D
on the SW. Quartz formation — origin of pebbles in
old formation — Centre fossil wood in quartz
Agate pebbles — Salinas — [*plains* deleted] *probably Some*
[*diluv* crossed out] 12E
modern or Tertiary Series —

Monday 15th — I see the Greenstone of 1st day consists of
a dyke about 100 yards wide — the Strata on opposite 12F
side; almost a coal — (Mem: Sandstone & black
lines in Quarry) vertical and disturbed: — No doubt [word or letter?]
Arthurs Coal — Again along the road; greenstones
alternate with Sedimentary rocks — Mem: case on coast 12G

Commentary

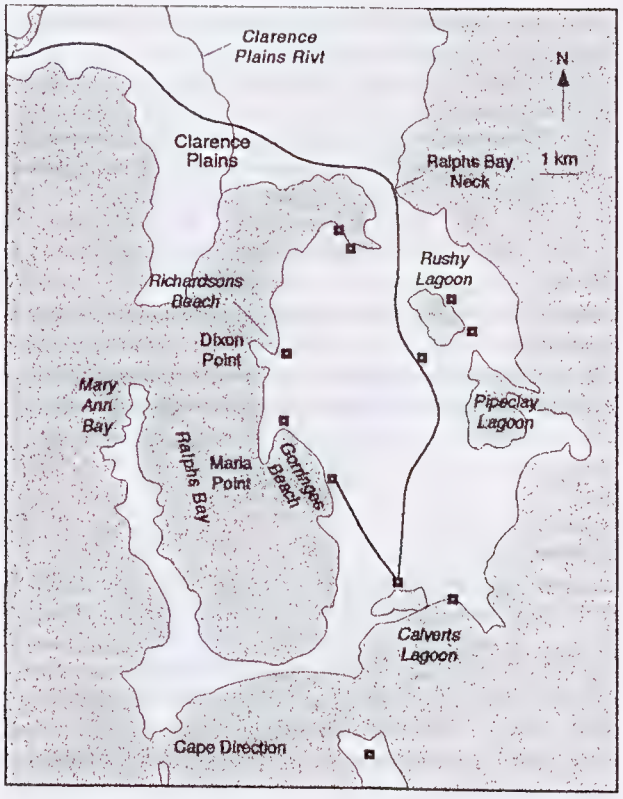
12A: The *Blue Limestone* probably refers to the Permian limestones which were being worked near Hobart at the time of Darwin's visit. He saw one such limestone on 15 February.
12B: Darwin again suggested a *trifling rise* but doesn't seem to have been at all certain about it.
12C: Darwin's information almost certainly came from George Frankland.
12D: *Granite* had been reported in northeastern Tasmania by the French explorers under Baudin (Péron 1807), the *Quartz formation* in the southwest by Matthew Flinders (1801) but Darwin may have got this information from Frankland. (See also Comment 8B.)
12E: Salt had been reported in salt pans (*salinas*) in the Midlands of Tasmania by A.W.L. Humphrey as early as 1809 (*Historical Records of Australia* [H.R.A.] III (1): 431, 769-770). *diluv* - short for "diluvium", the origin of which was a topic of considerable debate in geological circles early in the 19th century.
12F: This locality could be the former quarry, now occupied by Clare St Oval, or a nearby cut or low embankment on what is now Augusta Road (fig. 2), more likely the latter. The reference to *the Greenstone of the 1st day* is puzzling unless Darwin had been as far as New Town on 6 or 7 February. We have no other evidence that he went as far as that.
12G: *Mem: case on coast* may well refer to the situation on the shoreline below the Government Domain south of the present site of the Tasman Bridge. Along this stretch of shore outcrops of sandstone and dolerite alternate. Darwin probably saw this stretch of coast on Sunday, 7 February. [See also note 11G.]

(X13
in Government domain = limestone foot of M. 13A
Wellington opposite side of my ascent — mass of strata
occurring with organic strata [*Blackish brown* inserted];
[*Blue* hatched out in pencil] *compact Crystalline;*
occurs with slaty impure limestone— Organic remains chiefly
Terebratula [inserted *impressions of a Pecten*] *& beds composed*
of small oysters like at Isd
of Maria — Dendritic Manganese — Corallines chiefly 13B
occur in the Siliceous strata. — Stratification not 13C
quite regular — very rare pebble — uneven stratum
of white pulverulent Calcareous [*Aluminous* deleted] *Substance,*
used to burn with Limestone — singular aspect 13D
---
on road to New Norfolk — we met the very same —
stone — This formation much stratified — & strata not
very much tilted, only very little — Perhaps S.W. ? —
[next five words bracketed but line of bracket is partially hatched out]
(Whole town & valley of Derwent, newer formation). —
old sst, alternate with much Trappean rock — At 13E
New Norfolk, white rocks, similar to those of Kangaroo
point — Some more brittle. coarse & siliceous ( )
Some few pebbles, all siliceous & greater number
pure [*White* underlined twice and inserted] *quartz: Higher*
parts of hill had reddish
Sandstone:— General occurrence: — 13F

Very frequent beds of shells from 6 to 10 ft above the breaking 13G
of highest tides, on shores of Derwent, where now the water is
either fresh or at most brackish & no shells exist
I think an elevation would account for this change of
level & state of water — form of small, flat-bottomed 13H
creek line valleys: [sketch here; see plate 3] — *banks of shingle*
[underlined twice] *interstratified*
with such Shells. —

Commentary

13A: "=" probably the symbol used by Darwin to indicate horizontal beds. The *foot of M. Wellington* etc. refers to a former quarry beside Barossa Rd, Glenorchy.



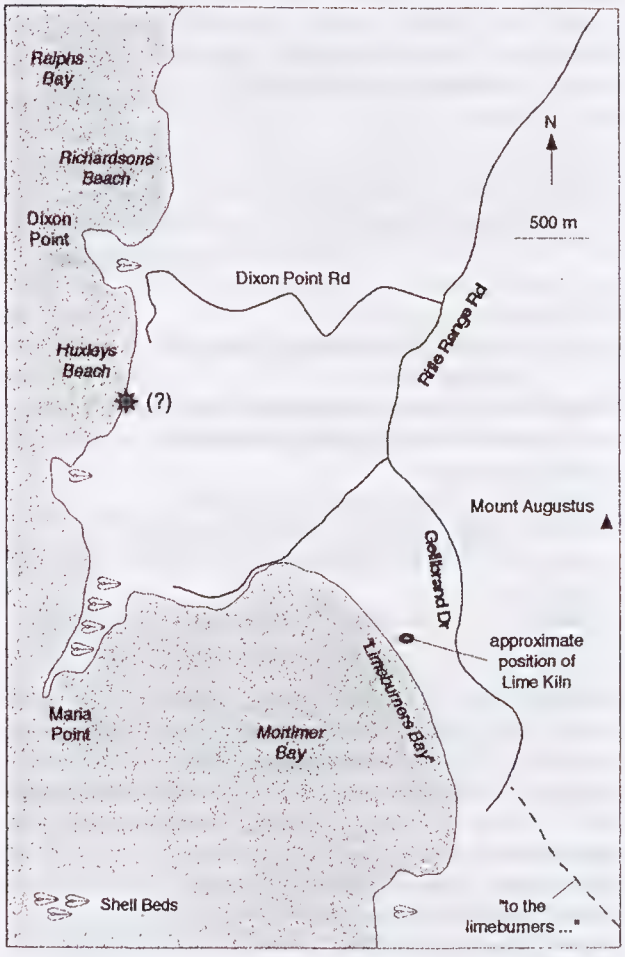


FIG. 6 — (A) A tracing of part of Hebert's map (1830) showing the track to Calverts Lagoon and Gorringes Beach and buildings south of Ralphs Bay Neck. (B) Tracing of part of the TAROONA *1:25 000 topographic sheet showing possible Darwin site, positions of elevated shell beds and track and name of bay from map "Monmouth Pt Ralphs Bay by Wm Dawson" (Monmouth 26, DELM).*

13B: *Dendritic Manganese* i.e. dendrites. The *Corallines* (bryozoans) are more obvious in the siltstone (*Siliceous Strata*) than in the limestone.
13C: The bedding surfaces in the limestone outcrop seen by Darwin are slightly wavy.
13D: *Singular aspect* presumably refers to the association of limestone and calcareous travertine.

This comment introduces his observations during his coach trip on 16 February (fig. 1). Limestone and travertine similar to that at Barossa Rd occur beside the road to New Norfolk, close to Altamont Creek, where lime kilns formerly operated.
13E: The *old sst* (*sst* is abbreviation of sandstone) is probably the Triassic but could be, in part, the sandstone in the Malbina Formation. The *white rocks* noted on the next line refer to the Fern Tree Mudstone.
13F: *reddish Sandstone* is Triassic, as is rock of the same appearance on Mornington Hill (Comment 4A). Above Fern Tree Mudstone at Derwent Cliffs and Derbyshire Rocks close to the bank of the Derwent River just below New Norfolk, Triassic sandstone outcrops (Leaman 1972). Darwin could readily have seen this sandstone by looking north from New Norfolk but the colour is not obvious.
13G: The sentence beginning *Very frequent ...* refers to the area above Granton where the delta of the Derwent River occurs and water may be somewhat brackish. No beds of shells are now visible from the highway.

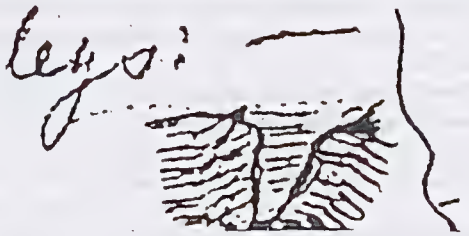


PLATE 3
Copy of Darwin's sketch to illustrate the valleys seen beside the Derwent on the way to New Norfolk on 16 February 1836.

13H: Many such flat-bottomed valleys (pl. 3) occur upstream from Goulds Lagoon (fig. 1) at least as far as Sorell Creek, about four kilometres east of New Norfolk. The flat bottoms, the flood plains of the streams, are little above the level of the Derwent River and probably graded to it. Darwin, in his memo (footnote (b) on the back of p. 18), postulated that they had been the floors of little coves.

(Page crossed through and overwritten: *Hobart town* in thicker darker ink; it is the unnumbered verso of page X13 and was used as a cover for the other pages i.e. 1–X13; for convenience it is quoted below as "[14]". It is partly a diary of the last six days of Darwin's visit, partly a series of memos about social matters, and partly a geological memo.)

[14]
Friday 12th — Called on Surveyor General Mr
Frankland. — Walked to Lime Kilns & Government [14]A
Garden =. Sandstone traversed Dined with
him in evening. [14]B
Saturday 13th — Crossed ferry — Rode to examine
beds of Shells — Very nice country. However [or *House* ?] [14]C
returned to. — Dined Attorney General
Very pleasant Musical perf [ormance?]. *very comfortable*
[*house* off page?]
large numerous rooms. beautifully furnished
Very pleasant guest [?] *party —*
Sunday 14th. Staied on board writing letters
Stopped for want of sun
Monday 15th — Mr Frankland came on board. Went
out riding with him — stormy day — dined in
evening most pleasant:=
Tuesday 16th — Went in coach to New Norfolk
banks of the Derwent — farms — very nice country:
mountainous — woody = Walked from town & fell asleep
beneath a tree. —
Wednesday — 17th Sailed — Mr Duff —
.....
on the whole like Hobart town better
Blacks removed [?]. *— excellent police — probably less* [14]D
crime than England. — [At bottom in deeper ink and finer script]
N.B. Quartz = pebbles in F.W. Limestone [above this
& Siliceous Sandstone]. [14]E

Commentary

[14]A: *Lime Kilns,* i.e. Shoobridge's Lime Kilns above Burnett Street; the *Government Garden* later became the Royal Tasmanian Botanical Gardens.

[14]B: Triassic sandstones occupy much of the Central Hobart– North Hobart area and would have been exposed as low benches.

[14]C: Darwin and Franklin crossed the river to Bellerive but, beyond that the locality of the shell beds to which Darwin and Frankland rode is uncertain. The matter is more fully considered below ("Challenges Disinterred").

[14]D: A reference to the removal of the Aborigines to Flinders Island a few years earlier.

[14]E: reference to the presence of siliceous pebbles in the rocks at Shoobridge's Lime Quarry and in the Permian sandstone on Porter Hill (see p. ***XII*** and Comment 8F).

INFORMATION NEWLY AVAILABLE

The field notes reveal more detail than later documents of Darwin's activities while in the Hobart area, with observations on, and deductions about, the geology not previously published. The new material on the route of his excursions will be dealt with first, followed by the new material on the Permian to Tertiary rocks in stratigraphic order, information on the structure, changes in sea-level and finally the marine fauna and flora.

Excursions and Excursion Routes

As noted earlier, Darwin made several "pleasant little excursions" during his visit to Hobart Town. Possibly that to Mt Wellington was not quite as pleasant as some (Comment 10A) but, compared to his excursions in South America and over the Blue Mountains from Sydney, they were probably pleasant and little.

It can now be shown that on Monday, 8 February, Darwin took the ferry across the river, and then walked around the shoreline as far as Howrah, inland to Knopwood Hill and back to the ferry over Mornington Hill (Comments 2D to 4A), not, as thought earlier, up Flagstaff Hill. Syms Covington, who noted that he had accompanied Darwin over the river and to Mt Wellington at least (but probably on most of his excursions), recorded that "steam ferries cross the river almost every hour" and that the trip cost sixpence.

In his walk south along the western shore on the following day, Darwin climbed Porter Hill (Comments 7C, 8E).

Rocks

Permian

Darwin reported, probably incorrectly, that the corallines in the rocks on the shoreline at Porter Hill were silicified (Comment 8A). He noted dendrites in the limestone at Barossa Rd [Comment 13B), limestone on the road to New Norfolk (Comment 13D), the Malbina Formation on the slopes of Porter Hill (Comment 8E) and ferruginous veins in the Fern Tree Mudstone on the foreshore at Bellerive (field notes, p.2).

Triassic

He recorded sandstone near New Norfolk like that at Mornington Hill (Comment 13E, 13F) and the free nature of some sandstone in or near the Government Domain (Comment 11F).

Dolerite

The field notes extend knowledge of his observations on the greenstone (Comments 1D and 5A).

Tertiary

Darwin must have looked quite closely at the Tertiary sedimentary rocks under the basalt at the southern end of Long Beach to have noticed the angular blocks of white mudstone in the bedded silts and clays (Comment 5E) and possibly at Cornelian Bay. The Tertiary limestone from above Burnett Street, West Hobart, first described by Darwin, is a puzzle taken up below ("Challenges Disinterred").

In the basaltic rocks in the crater at Sandy Bay, he noticed "jaspery and Porcelain rock" (Comment 6C).

Post-Tertiary

In the field notes he used the term *Salinas* (Comment 12E), probably one he picked up in South America, in writing of the ponds with salt referred to in the memo on p.15.

Stratigraphic Relationships

Comments 7D and 8G show that Darwin correctly inferred the age of the dolerite relative to the fossiliferous sedimentary rocks at Lower Sandy Bay and he noted that the Fern Tree Mudstone at New Norfolk lies under the red Triassic sandstones (Comment 13F), a relationship he also inferred at Bellerive and on the slopes of Mt Wellington. From his observations he concluded that there were three sandstone horizons in the area (Comment 9A) and that the latest, the

Tertiary, formed a fringe beside the Derwent River e.g. Cornelian Bay, Marieville Esplanade and at Long Beach, Sandy Bay, a distribution also noted and expanded by Johnston (1882). He was not always clear, however, as to which of the three horizons a particular outcrop belonged, a difficulty which has also confronted later geologists.

Correlations

Darwin made some local correlations, some in agreement with later views, others not. He saw the similarity between the limestone at Barossa Road and that on the New Norfolk Road at Altamont (Comment 13D). He correctly related Permian and Triassic rocks at Bellerive with those close to New Norfolk (Comments 13E, 13F) but with some uncertain. He correlated, incorrectly, the Fern Tree Mudstone (Permian) at Bellerive with the sandstone (Triassic) of the city area (Comment 2G). Part of the problem may reflect variations in grainsize within the younger Permian siltstone sequences. Some beds are predominantly of mud-sized fragments, others of fine sand; most are very poorly sorted, producing the impression of a rock with sand-size grains. The siltstone sequence does include better sorted but pebbly sandstones. The Triassic succession contains well-sorted rocks, but some are fine-grained and may have characteristic cross bedding or fine bedding. Where exposure is restricted, some of the finer members may appear similar to some Permian siltstone — in colour as well as texture. Darwin was not correct in suggesting that the basalt at Sandy Bay (Tertiary) was of the same age as the dolerite (Jurassic) near the mouth of Storm Bay (Comment 6D). A careful analysis of his envisaged age relationships reveals that he had gained insufficient information in this area to allow the construction of a stratigraphic framework.

Darwin did, however, see the similarity of the rocks, particularly the Triassic rocks, near Hobart to those around Sydney (Comment 1C). He suggested a similarity between the fossils in the Permian rocks around Hobart with those of the Carboniferous limestones of Argyll (Comment 7G), which was plausible within the constraints of the knowledge at the time.

Geological Structure

Darwin made few remarks about the geological structure (Comments 1A, 3E, and pp. *1, 2, 6, X13*) and had no clear picture of the general structure of the district which is scarcely surprising. Even now much remains to be done to understand the structure fully.

Changes in the Relative Level of Land and Sea; Shell Beds

More information is now available about the places Darwin may have visited during his ride with George Frankland to see the shell beds at Ralphs Bay (see "Challenges Disinterred" below). The field notes reveal that Darwin saw beds of shells at higher levels than he reported in later works and provide more detail of the shingles with Serpula-encrusted boulders (Comments 9C, 11H, 11I, 13G).

While he was aware of the possibility of confusion of shell beds and native middens, and although he had criteria for distinguishing one from another, he did not always succeed in doing so.

The little flat-floored valleys were noted, such being a feature of several of the tributaries flowing into the western side of the Derwent River above Goulds Lagoon (Comment 13H).

Further, Darwin commented on the depth of water in the coves bordering the Derwent River and attributed this condition to subsidence (Comments 2I, 3A; see also "Challenges Disinterred" below).

Marine Fauna and Flora

Darwin noted the similarity of the marine flora and fauna in the Derwent River to those near Sydney (Comment 2I).

A GENERAL COMMENT AND DARWIN'S MODE OF FIELD OPERATION

These previously unpublished observations and deductions reinforce earlier suggestions (Banks 1971) as to the astuteness of Darwin's observations and of his geological deductions. They represent a very creditable total for nine days fieldwork.

It is appropriate at this stage to consider briefly what his field notes and memo reveal about Darwin's mode of operation as a geologist. At the strategic level of designing his field programme, Darwin noted the outcrops in cliffs and on the shoreline as the *Beagle* sailed up the Derwent, and he remarked on Mt Wellington. Soon after reaching Hobart, he seems to have made contact with the Surveyor-General George Frankland (see later). From Frankland he could well have learnt of interesting sites close to the town, e.g. the lime quarry. After that meeting he could have decided on the broad outline of his "excursions" — visits to the shoreline on eastern and western bank of the river, Mt Wellington and interesting places. So he went east and southeast, south, west and north. Noting the ebb and flow of the tides, he may even have decided on when he would visit the shoreline exposures.

When he reached the outcrops, he observed clearly and closely — Geikie (1909: 6) noted that he had "sharp enough eyes", an attribute well borne out in his work around Hobart Town. What he saw he interpreted in the light of his already very considerable experience (see the early chapters of Darwin by Desmond & Moore [1991] for details of his early life; the points judged relevant are summarised below).

His early education was first in classes taken by a Unitarian minister and then in the Anglican Shrewsbury School. In Edinburgh, a hot-bed of radicalism at the time, he joined the Wernerian Natural History Society and came into contact with Professor Robert Jameson, a "Neptunist", who attributed great importance, as did Werner, to a hypothetical global, encompassing ocean in the history of the earth and in the origin of rocks. Darwin had the opportunity to take practical classes in mineralogy while in Edinburgh and to make geological excursions. Later, at Cambridge University, one of the pillars of the Anglican establishment, he attended soirées for budding naturalists, events attended also by Adam Sedgwick, Professor of Geology, whose lectures Darwin attended. Sedgwick had very different views of the Earth from Jameson; he was a "Plutonist", a believer in the igneous, as opposed to aqeous origin of

granite, and a "Catastrophist" (a believer in the occurrence of major convulsions and catastrophes during the history of the Earth). In the summer of 1831, Darwin carried out geological mapping around his home in Shrewsbury and later joined Sedgwick in mapping in North Wales,where he was given the opportunity to map some areas on his own. Darwin was encouraged to read Charles Lyell's *Principles of Geology* after the publication of the first volume of that work in 1830. Lyell was also a "Plutonist" but, as a "Uniformitarian", he did not accept the views of the catastrophists but thought that present geological processes had operated in the past at about the same intensity as they do now. Thus, from his "mentors", Darwin was exposed to all the important shades of contemporary geological philosophy. And then he boarded the *Beagle*!

By the time he reached Hobart, he had experienced climatic zones from the tropical to the polar, been exposed to conditions from sea-level to the high mountains of the Andes and been able to observe the processes operating over that range. He had experienced tropical rain forest and a cool temperate desert. Geologically he had seen a variety of minerals, flat-lying rocks and strongly folded rocks, igneous rocks from granites to basalts, glaciers carving the land surface, ice bergs floating on the sea and volcanoes erupting; he had experienced an earthquake and seen the effects of a major one.Thus, he had fitted into his voyage a great wealth and range of experiences of geological phenomena.

In observing and thinking about geological features near Hobart, he observed clearly and closely, and then placed his observations in the context of his intellectual and earlier geological background. He was not observing "blindly" nor "thinking" in a vacuum or in a straitjacket of a particular philosophy. He came from a family of dissenters, had been educated in dissenting and establishment institutions, and had been exposed to the full gamut of geological philosophies. He interpreted what he saw with a well-filled but open mind. His explanations were, however, predominantly "uniformitarian".

THE DIFFERENCES BETWEEN TEXTS

Darwin reported observations, deductions, impressions and ideas about his time in Hobart Town and surrounds in at least four forms — field notes (FN), a memo (M), a published *Journal* (1839a, b) (J) and a book, *Observations on Volcanic Islands* (1844) (V). As might be expected, the contents and structures of the four records differ in accord with the functions and circumstances of production of each.

The Field Notes (FN)

The field notes are to a considerable extent a record of his observations almost as he made them in the field, his immediate thoughts and deductions and brief comments to act as memory joggers. The structure of the field notes is virtually, as might be expected, chronological, with references to other parts of Tasmania or the world made where appropriate. The notes include a sketch of a flat-floored valley. In terms of the local scene, the notes are the most informative.

It is clear that within a day or so of reaching Hobart Town, Darwin had met George Frankland and talked at length with him, with the result that he was able to make comments about the geology of parts of Van Diemen's Land (VDL) he did not see. In several places the notes reveal that he recognised similarities between what he was seeing in the field in VDL and what he had seen in Scotland before his voyage began (e.g. *Mem. limestone of Argyl*) or during the voyage with references to Port Famine, Chiloe, New Zealand, Sydney and others.

Darwin noted in the field notes [2F, 8B, 8C] that there are pebbles of several rock types in the fossiliferous (Permian) strata, pebbles now interpreted as ice-rafted dropstones. In one of his notebooks in Down House Museum, Downe, Kent, UK (Darwin's former home, where his instruments are also preserved) (RN: 21), Darwin wrote "There is a resemblance at Hobart Town between the older strata and the bottom of the sea near T. del Fuego". Banks (1971: 17) interpreted this comment to mean that Darwin attributed the pebbles he had noted in the Permian fossiliferous rock near Hobart to ice transport by analogy with those he had seen on the sea floor off southernmost South America (Darwin 1846). In none of Darwin's published statements was this resemblance mentioned. It has been suggested (Banks *et al.* 1987: 233) that Darwin was hesitant to propose at a time when there was a fierce debate about the past extent of Quaternary glaciers, that glaciers (spawning icebergs as they do now in Tierra del Fuego) were present late in the Palaeozoic. It was not until 1852 that Ramsay even hinted for the first time that there may have been ancient glaciations, and not until 1855 did he explicitly infer the existence of Late Palaeozoic glaciers. Darwin may well have thought that he did not have sufficient evidence to convince a sceptical audience. This situation can be contrasted with the almost immediate publication of his ideas on the origin of coral reefs with which he was comfortable and for which he had considerable evidence. The glaciation situation is more comparable with his hesitation in publishing his thoughts on evolution. There are still debates on ancient glaciation and on evolution.

In the field notes he recorded the observation that the mudstone on Knopwood Hill was altered (3E) but did not explicitly say that the *greenstone* had caused the alteration. He shortly thereafter (top of his p. 4) used the word "*Metamorphised*" but the text is not clear enough to decide what he thought might have been "*Metamorphised*". In the memo (p. 1) he noted the presence of *Porcelain rock and indurated sandstone, lying in the lines of junction, point out the effect of an igneous mass* (the *greenstone*, i.e. dolerite). He also inferred that coal (*Arthurs Coal*) had been disturbed close to the dyke.These observations on metamorphism were important in potentially demonstrating that the dolerite was intrusive into the Permian Fern Tree Mudstone on Knopwood Hill and into the Triassic coal measures near New Town, both sedimentary rocks being regarded as "Carboniferous" by Darwin. Darwin used the lack of pebbles of *greenstone* in the fossiliferous rocks and higher units on Porter Hill to suggest that the dolerite was younger than the sedimentary rocks (see comment 7D). These observations on the relative ages of the dolerite and sedimentary rocks were not published by Darwin. This omission was regrettable in the light of subsequent history — it was not until over 60 years later (Twelvetrees & Petterd 1900) that the vexed question of the relationship of the dolerite to the sedimentary rocks was satisfactorily resolved, largely using, *inter alia*, the criteria that Darwin had observed.

The Memo (M)

The memo is clearly a later production than the field notes. It contains information on the mineralogy of the dolerite which would have required access to his microscope, such access being possible while the *Beagle* was still in Hobart Town. He incorporated in the memo observations on specimens which included those recorded in the field notes but others in addition. Some references, e.g. to Scott, MacCulloch and others, occur in the memo and may have been made after the *Beagle* left Hobart. It seems possible, even likely, that Darwin wrote most of the memo during the voyage from Hobart Town (sailed on 17 February) to King George Sound in Western Australia (reached 6 March). Armstrong (1985: 6) suggested such a possibility.

The function of the memo is not clear but it was certainly written with geologists in mind. It may have been a first attempt to get the field notes into the sort of order appropriate to a systematic account of the geology of the Hobart area, perhaps a preliminary to a later paper or chapter in a book. It is clearly only a first attempt and the structure is difficult to discern. A section on the geology of the town area is followed by an account of an excursion along the western shore of the Derwent River south of the Town. The *singular assemblage* of fossiliferous sedimentary rocks (i.e. the Permian) is next considered in its various occurrences including observations made on them on the eastern shore, followed by treatment of the *greenstone* (dolerite) which includes the comment that the rock strongly affects the magnetic needle on Mt Wellington, although no mention of this property appears in the field notes. Robert Brown had noted this phenomenon late in May, 1804 (Robert Brown's *Diary*, Botany Library, Museum of Natural History, London; see Leaman 1997) and Flinders (1814: clxxxviii) reported in a footnote that

> Upon the top of Mount Table, the compass has since been found to vary as much as 20°, from one part of the mountain to another.

The Flinders volume was on the *Beagle* (Burckhardt & Smith 1985, appendix to Volume 1: 569). Brief mention of the apparent surface seen from Mt Wellington then precedes sections on the geology of other parts of VDL, an extensive treatment of the limestone quarry in West Hobart, uplift of the land and finally a summary of the geological history of VDL and correlations with Argyll, NSW and New Zealand.

The reader is left with a confused idea on the geology for, as noted earlier, Darwin was, understandably, not entirely clear in his own mind on the order of geological events. He may have intended to write it up more systematically later but have realised that he had insufficient data with which to do this, particularly as there were many pressing and more important demands upon his time once he returned to England. Indeed, he wrote to W. Fox from Hobart Town on 15 February (Burckhardt & Smith 1985, Vol. 1: 491–492)

> I draw up very imperfect sketches of the Geology of all the places to which we pay flying visits, but they cannot be of much use. Leaving America, all connected and therefore interesting, series of observations have come to an end …

As noted above, Darwin recorded similarities between what he saw in the vicinity of Hobart Town and what he had seen earlier in Scotland or during his voyage. He made no reference in the field notes to publications. In the memo, Darwin did, however, refer to a number of publications. These references include two which might be regarded as practical manuals, D'Aubisson (1819) and MacCulloch (1821), and others which were works about VDL, e.g. Bailly in Péron (1807), Flinders (1801, 1814), Lesson (in Duperrey 1830) and Scott (1824). It seems likely that Darwin brought the manuals, and perhaps other volumes (e.g. Péron, Flinders 1801 and Scott), on board with him and the others may have been on board as part of the extensive library known to have been on the *Beagle* (Armstrong 1985: 10, Burckhardt & Smith 1985: appendix 1, Desmond & Moore 1991: 107).

The Journal (J)

The main points made by Darwin in the Van Diemen's Land section in his published *Journal* concerned social matters — the aborigines, the town, gardens, public order and commerce, with the flora including the tree ferns and gums, and the climate also receiving attention. Darwin (1839a: 535) wrote of emigration and in his diary (Keynes 1988: 409–410) occur the words " if I emigrate, choose this rather than Sydney". Later, on the same theme, he wrote to the botanist, Joseph Hooker on 1 March 1854 (Burckhardt & Smith 1985, Vol. 5: 180–181)

> … it is a very *remarkable* and creditable fact to the Colony: I am always building veritable castles-in the air about emigrating, & Tasmania has been my head-quarters of late, so that I feel very proud of my adopted country.

This comment arose upon Darwin hearing from Hooker that the Executive Council of VDL had voted him (Hooker) £350 "in acknowledgement of my past and coming services to Tasmanian Botany" (Burckhardt & Smith 1985, Vol 5: 178).

He made some note of the limestone at West Hobart, *a solitary and superficial patch of yellowish limestone or travertine*, and passing mention of the highly fossiliferous nature of some of the strata and of the small rise in the land. This publication was an account for public information.

A new comparison emerges in the *Journal* between Bell Mountain in Chile and Mt Wellington (*Narrative* and subsequent editions). In referring to Bell Mountain, Darwin (1839a: 313) noted the large accumulations of loose boulders near the summit which he believed to be due to "frequent earthquakes". On the following page, he commented "Mt Wellington, near Hobart Town, … summit similarly composed and similarly shattered …". Six years later (J 1845: 259), in commenting on this matter he wrote "Mt Wellington, in Van Diemen's Land, where earthquakes do not occur …". He did, however, further comment in respect of Mt Wellington "all the blocks appeared as if they had been hurled into their present position thousands of years ago". Geologist now tend to assign the accumulation of loose boulders on the slopes of Mt Wellington ("block fields") to periglacial activity and creep, but seismic activity may have been a factor in the

longer term. A few earthquakes have occurred along the Derwent south of Bridgewater in historic time and others are likely to have occurred in the area since the block fields began to form, presumably during the Pleistocene ice age.

Geological Observations on Volcanic Islands (V)

The limestone (travertine) was the prime point of interest in the published account Darwin produced for geologists — *Geological Observations on the Volcanic Islands* ... (1844) — with the uplift of the land as his second main interest. In keeping with the title of the book, Darwin gave considerable detail about the volcanic crater at Sandy Bay. The Permian rocks also engaged his attention for their indeterminate character (mineralogy and unusual texture) and abundance of fossils. Triassic rocks, coal measures and dolerite, and the pre-Permian rocks found elsewhere in VDL were minor to passing themes. Very importantly, he included in the book descriptions made by British experts W. Lonsdale and G.B. Sowerby of some of the fossils he collected. The fossils allowed a statement on the age of the rocks to be offered, a statement which, although wrong on present information — if only just — was the best answer available at the time he wrote (i.e. Carboniferous; they are now known to be early Permian, but the Permian System had not been proposed at the time of the *Beagle* voyage). With the exception of the first few lines, which deal with the greenstone as the main component of the mountains, the account in *Geological Observations* ... moves from the oldest to the youngest rocks, picking out points of general geological interest and minimising local detail. About a quarter of the section on Van Diemens Land deals with "Elevation of the land".

DARWIN'S INSTRUMENTS AND MEASUREMENTS

Darwin quoted the height of Mt Wellington as 3100 ft (944 m) in his memo (p.11) and noted that this figure was based on angular measurement from the *Beagle*. He also quoted (p. 11) the height of the top of the sandstone on the mountain as 1200 ft (366 m). Both figures were repeated in later publications.

The height now accepted for Mt Wellington is 1271 m, so that the height quoted by Darwin was much too low. This is surprising in view of the fact that some older maps, e.g. that of Hebert (1830), gave heights approaching 4000 ft — Hebert gave it as 3800 (i.e. 1158 m). It seems highly unlikely that the measurement of the angle of elevation from the *Beagle* to the top of the mountain was seriously in error, which implies that the assumed horizontal distance from the *Beagle* to the summit was far too low. Another possibility is that the original recording of the figures was incorrect and, once having been recorded, was simply repeated.

The height quoted for the top of the sandstone was also far too low. It should be about 920 m, i.e. about 560 m above that given by Darwin. If the assumption is made that the figure of 1200 ft was measured accurately by barometer, the position could have been at Halls Saddle, near the head of Wellington Rivulet, a locality quite likely to have been on Darwin's route as he climbed Mt Wellington on 11 February. Sandstone certainly crops out to almost that position. Beyond it is mudstone, which may not have outcropped on the tracks taken and, if Darwin followed tracks to the first or second spur beyond the present site of Fern Tree before beginning the ascent of the *damp southern side of the mountain*, he could well have seen nothing but dolerite talus and thick vegetation during most of the climb to the summit.

Darwin's instruments are preserved at Down House. Miss Strachey, Curator with Down House, informed us that Darwin had a barometer, labelled "Newman's Portable Iron Cistern, 122 Regent Street, London". He also had with him a combined compass and clinometer made to his own specifications by Cary, London. In V he quoted heights of several places stated as measured by barometer; he also quoted heights he stated as estimated, in some instances to the nearest foot, in others to the nearest ten or hundred or thousand feet. He quoted the heights of the Blue Mountains west of Sydney accurately. He may have constructed a simple staff for use with the clinometer in measuring heights but, as far as we know, made no mention of measurements made by such a device. It seems likely in the absence of mention of a level in his list of instruments, that the heights he quoted for shell beds around the Derwent were estimated heights.

When Darwin quoted directions, it was mostly in terms of the points of the compass e.g. NE by N, but, in a few instances, he quoted the actual direction e.g. E.57°N. In quoting angles of dip of geological features, he used descriptive terms, e.g. horizontal, gentle, high, etc., in some places; in others, a range of values, e.g. 30° to 40°, 30° to 36°; in a few cases both dip angle and direction, e.g. 12° to N, were quoted. His practices in these respects seem appropriate to the reconnaissance type of geology he was mostly doing.

CHALLENGES DISINTERRED

Introduction

In reading Darwin's field notes it became clear that while some of the problems recognised by Darwin or arising from his observations have now been solved (e.g. stratigraphy of the Permian and Triassic rocks, age and relationship of the dolerite to the sedimentary rocks), others remain unresolved even now, including the distribution of shell beds around Ralphs Bay, the origin of the limestone in the Burnett Street Quarry and its structure, the history of relative movements of land and sea along the Derwent River, and the causes, e.g. seismic activity or other process, of such movement. The challenges posed by such unresolved problems will now be addressed.

The Ride to Ralphs Bay and the Early Burning of Limestone

It seems likely that Darwin expressed to George Frankland at an early stage in their association his interest in relative movements of land and sea and the significance of shell beds in casting light on such movements. Frankland was probably aware of the occurrence of shell beds near the shores of Ralphs Bay and the suggestion of a joint excursion would naturally arise.

It is not clearly stated in any of Darwin's texts where the "beds of Shells" (FN) were which they rode to examine. The site appears as "In Ralphs Bay ..." (M), and "on the shore of Ralph Bay ..." (V) and Frankland would have known that shells had been burnt for lime in the Ralphs Bay area for several decades.

A map by Hebert (1830, and fig. 6A herewith) shows a track from the ferry wharf at Bellerive, south through Clarence Plains, now Rokeby, to the neck at Ralphs Bay, beyond which it passed west of Rushy Lagoon, near the southeastern margin of which a building was shown, west of Pipeclay Lagoon, reaching just north of Calverts Lagoon, where it turned NNW to reach a building just behind the shoreline of what is now called Gorringes Beach. This map showed a building north of Maria Point and another just north of Dixon Point but none just south of Gorringes Beach. A map in the Archives of the Department of Environment and Land Management (DELM), "Monmouth 26" by Mr Dawson, a surveyor (1831–36) under George Frankland, shows Mortimer's property and, near the southeastern corner of that property, a track with the words " To the limeburners' point [or punt or ...]" in pencil, and, in the area just off the beach, "Limeburners Bay", an insertion of unknown date and authorship (Mr Bill Reid, DELM). On this map a structure is shown in the same position, just behind Gorringes Beach, as the building on Hebert's map, but in addition one is shown on the hill south of Gorringes Beach and also shown on Frankland's 1839 map. Frankland's map of Tasmania shows the bay as "Mortimers Bay", so it is likely that Dawson's map was produced before 1839. Mortimer owned the property behind Gorringes Beach at one stage, the house being on the hill to the south of the beach, just behind Gorringes Jetty, shown on a map, Monmouth 3 (28.5.1939), a little to the south of the end of Gorringes Beach. The structure behind the middle of Gorringes Beach may have been the limeburners' hut, but it is not labelled. Small creeks flow into Mortimers Bay close to the position of the "hut" and could have supplied the water needed to slake the quicklime obtained from burning the shells. The lime would need to have been slaked prior to transport by water, as quicklime reacts readily with water, with production of much heat.The lime-burners' hut was stated to be about 2 miles (3 km) from Mr McCauley's house and was reached by water from Hobart (Nicholls 1977: 137, 141, 154). The McCauleys lived at Waterloo Farm just southeast of Rushy Lagoon (probably the building shown on Hebert's map) about 3.5 km from Gorringes Beach (Hudspeth *et al.* 1994).

Shells were being burnt to produce lime near Sandford as early as 1806 (HRA, Series III, Vol. 1: 539). Shells are abundant at Gorringes Beach, and there are thick accumulations, some partly cemented, in the foredune and the next dune inland. In places there are signs that pits have been excavated in these dunes. Mrs Audrey Hudspeth (letter 4.12.1997) drew attention to an advertisement in the *Hobart Town Courier*; an advertisement over the name of H.W. Mortimer appeared on 29 June 1832, for "Oyster or Cockle Shell Lime", which, judging from the prices quoted, came from south of Hobart Town — at the kiln it was sixpence, at the wharf, one shilling, and at New Norfolk two shillings a bushel. Present outcrops of shell beds behind Gorringes Beach are only 1–2 m above high water mark.

Although shell beds are abundant on the Ralphs Bay side of the neck at Lauderdale, recent search has not yielded any evidence of shell beds a few metres above high-water mark; Mr Richard Lord, who spent holidays in the area as a boy, did not recall any being present fifty years or so ago. Higher level shell beds occur on the hill south of Gorringes Beach, on the ridge leading down to Maria Point and at Richardsons Beach (fig. 6).

On available information, it is likely that Darwin and Frankland rode to Mortimers Bay by the old road over Ralphs Bay neck and further south until they met the track to Gorringes Beach over Mt Augusta.They may well have returned to the neck by a coastal route including the property north of Maria Point and that north of Dixon Point.

The "Burnett Street" Lime Quarry

The limestone above the top end of Burnett Street (fig. 2) was discovered by two convicts, McCoy and Boon in 1813 (HRA 111(2): 41); quarrying started soon afterwards. Darwin's comments were the first of a geological nature on it, there being comments by Strzelecki (1845), Jukes (1847), M'Cormack (1847), Milligan (1849) and Johnston (1882) later in the 19th century. Darwin recorded his initial observations in his field notes, and subsequently commented on it in the memo, his Journal and *Volcanic Islands* ... The geology and origin of this limestone formed one of the four main threads in his *Volcanic Islands* ... The occurrence is of some interest, first from being noted by Darwin, second because it contained fossils, probably figured by Strzelecki. However, the quarry has been filled in for many years and no satisfactory account of the stratigraphy and structure (nor any diagrams or photographs of it) have been published previously. It is a challenge.

The limestone was pale brown (FN) or pale yellow (M), porous, not very compact but hard (FN), contained cellular, linear cavities, pebbles of quartzose rock (FN and V) and quartz (M), and layers (FN) and nodules (M) of flint. Strzelecki (1845) noted four types of limestone, which differed in structure, texture and smell, some of them smelling argillaceous when moistened. The memo records a Darwin specimen number for flint from the quarry, the specimen presumably still being in the Sedgwick Museum in Cambridge, UK.

Leaves different from existing species were reported as impressions in the limestone by Darwin (FN), being particularly abundant in the lower layers (M). There were four or five kinds, including a trifid palmate frond (Darwin quoting Robert Brown in V). Strzelecki also reported Brown's findings and illustrated three of them (pl. V11, figs 5, 6 and 7), one showing the "aspect of a Proteaceous leaf" (1845: 254). Milligan (1849) also noted the leaves and suggested affinities with some modern Tasmanian species (e.g. the *Sassafras, Weinmannia, Banksia, Leptospermum* and *Phlebalium billardieri*, the trifid frond being perhaps a fern). Ettingshausen (1883) figured a fossil plant collected by Dr John Lhotsky from this quarry, "*Cinnamomum" woodwardi*, which is now in the Natural History Museum, London (OR 1301) (letters from Ms Tiffany Foster, Curator, Department of Palaeontology). Strzelecki (1845: 254) noted that specimens he illustrated came from the "yellowish compact limestone ... described by Mr Darwin" (his fig. 5 on pl. 7, OR 41176, ? *Phyllites*; his fig. 6,, OR 52610, labelled ?*Fagus*, and figure 7 based on V 19870, probably from the Stokes Collection).

Ettingshausen (1883) figured material from "Tertiary travertine, Hobart", which had been collected by Robert M'Cormack, surgeon with the Ross Expedition, and named *Salix cormickii* (V 13604), *Cinnamomum hobartianum* (V 13610) and *Echitonium obscurum* (V 13611). It is likely that these came from the quarry in Burnett Street as some of the specimens he collected were labelled specifically as from Geilston Bay or Lindisfarne, but these specimens were not.

Darwin reported land shells from the limestone (M, N) and two snails, which may have come from this quarry, were described by G.B. Sowerby and illustrated in Strzelecki (1845: 298, pl.XIX, figs 5, 6). Sowerby named them *Bulinus gunnii* and *Helix tasmaniensis*.. Some later geological visitors were unable to find the snails.

Darwin postulated an origin of the limestone beneath water in a small creek (FN), later (M) allowing the possibility of deposition in a lake. In *Volcanic Islands* ... he wrote of it as formed by a calcareous spring entering a small pool or narrow creek. A spring origin is indicated by the texture. Milligan (1849) postulated deposition in a "shallow sedgy valley, maintained chiefly by calcareous springs". The pebbles of quartzose rock and quartz could well have been derived from Triassic sandstone outcrops upstream from the spring, i.e. to the west.

The depth of the deposit was given as 9–12 m by Milligan (1849), but no internal stratigraphy or basement rock has been recorded. The limestone deposit was covered by *Wacke* (see Comment 11B, and pl. 2) as was the whole hill (FN). The wacke contained calcareo-aluminous matter and a few pebbles. It is assumed that the *calcareous (aluminous) matter* was a mixture of calcium carbonate which Darwin could have detected by its effloresence with dilute hydrochloric acid, and a clay mineral detected by its earthy smell after moistening, a feature noted by Strzelecki (1845). In fact, Milligan (1849) noted the presence of irregular beds, masses and nodules of clay and Fullers Earth (a form of the clay mineral, montmorillonite). Darwin (FN, M) noted that the *Wacke* occupied a fissure in the limestone and contained a rounded pebble (M, V). Milligan described the wacke as boulders of greenstone (dolerite) in clayey loam with encrusting and interstitial calcium carbonate and unusually shaped carbonate bodies which he interpreted as fossil fungi. The wacke rested on fossiliferous limestone, greenstone, sandstone, shale and claystone throughout the district and had a depth of 3–4.5 m. In 1853, Milligan (1854) reported lignitic wood near the base of a "diluvial boulder bed" about 7.5 m thick in a shaft at the head of Warwick Street, West Hobart, the bed resting on sandstone. This was presumably the wacke. The origin of the wacke did not receive specific attention. From his comments (V), it would seem that Darwin may have thought it to have been volcanic; Milligan (1849) saw it as "the result of the last great upheaving force" which raised the limestone to its present level.

Darwin recorded a dip of 45 to 50° for the limestone (FN,M; see pl. 2), the higher figure also reported by M'Cormack (1847), who stated that it was to the WSW. The limestone had been tilted and fissured after deposition (FN), with the wacke resting unconformably on it. The tilting was attributed by Darwin to a volcanic eruption which also covered it (V) and by Jukes (1847) to an adjacent trap intrusion. No evidence is now available of volcanic activity in the vicinity, a mafic dyke, cutting the Triassic rocks beside the nearby quarry at the head of Arthur Street, being dolerite, not a feeder to a Tertiary basaltic flow. An alternative explanation is that the wacke is a mass flow deposit shed from the upper slopes of an ancestral Knocklofty, which incorporated dolerite, sandstone and pebbles from the rocks over which it flowed and tilted, disrupted and covered the earlier, uncompacted spring deposit in its passage. Perhaps Milligan had the essence of the story as proposed above.

The carbonate in the spring deposit and in the overlying wacke, and the siliceous bodies in the spring deposit merit consideration. It is likely that both were deposited from groundwater which had acquired the calcium from the decomposition of minerals in the dolerite, and the silica from the same processes. Water falling on the ancestral Knocklofty would percolate through the dolerite, decomposing the feldspars and pyroxenes in it to yield calcium and other ions, and silicic acid in solution, and leaving residual clay minerals. Where such solutions came into contact with air and evaporated, calcium carbonate and silica would have been precipitated. Some other travertine deposits occur where dolerite has been intensely shattered or involved in mass flow deposits (e.g. Granton, Otago Bay).

The entire setting (Comment 11B) is consistent with this explanation i.e. a spring deposit later disrupted by a mass-flow down the slope of an ancestral Knocklofty.

Relative Movements of Land and Sea

A recurrent theme in Darwin's writings on the voyage of the *Beagle* is the relative movement of the land and the sea, commonly the uplift of the land so clearly seen by Darwin in South America. Oldroyd (1996: 177) noted that Darwin had associated uplift in South America with volcanic activity. In his writing on this subject as he saw it in the Hobart area, Darwin noted evidence of both uplift and subsidence of the land. He tended to think in terms of upward or downward movement of the surface of the lithosphere and hardly considered the possibility of the movement of the surface of the hydrosphere. The concept of eustatic movements of sea level controlled by changes in glacial ice volume was first mentioned in about 1842 (Dott 1992: 6–7) but not taken seriously for another 20 years.

Uplift

Taking first the evidence Darwin saw for uplift, he relied mainly on shell beds at various heights above sea level and to a lesser extent on shingle beds and on the geomorphology. He made it clear that elevated shell beds could be of one of three possible origins. In the first instance, they could be uplifted marine or littoral shell beds. Such an origin would be indicated by their occurrence in large numbers, in beds rather than in heaps (M), associated with rounded pebbles and interstratified with beds of shingle (M and V), and containing shells too small for eating. Prime evidence of a geological rather than a human origin for shell beds was his discovery of shells associated with pebbles encrusted with the tubes of marine (serpulid) worms.

Second, Darwin was aware that farmers might spread shells over their fields as fertiliser (FN: 9) but he did not see enough agricultural land to develop criteria for recognition of such an origin.

Third, Darwin also knew that the aborigines gathered shellfish for food and left the shells close to their campsites.

He expected such accumulations to be in heaps (FN, V) and associated with stone instruments e.g. hatchets (FN, M). The shells should be those of edible species and big enough to be worth gathering for food. The possibility of uplift of the land after accumulation of the heaps was noted (FN: X11). Uplift of an island after human occupation had been deduced by Darwin for the Island of San Lorenzo, off Callao, on the west coast of South America (J 1909: 375).

Darwin did not make clear how the heights of shell beds (etc.) were measured. Heights up to say 15 ft (4.5 m) are likely to have been estimated and to be reasonably accurate but higher figures must be regarded as approximate only.

Darwin wrote (FN: 2) *There appears to have been a general rise — Shells on sides in beds in very many parts.* The occurrence of shell beds at 1.8–3 m above the breaking of highest tides and interstratification with beds of shingle were seen by Darwin on the way to New Norfolk (FN: X13), referred to in the memo (p.18) but played down in *Volcanic Islands ...*, in which Darwin noted the possibility that tides might have been higher in the past. He noted that, in the areas where he saw the shell beds, the water is now fresh or brackish. Also on the way to New Norfolk, he saw flat-bottomed valleys close to high-water level (FN: X13), explained later (M, footnote b on the back of p. 18) as "the floors of little coves". He had earlier (FN: 9) reported shells at 3 m to 9 and 12 m *all along fields ... Comminuted* after having walked along the shoreline south of Bellerive and walked back from Porter Hill, probably along along the cart track through the farmlands of Sandy Bay on the western shore. He reported the shells as being *very much spread ... on a small scale, few pebbles on upper surface,* but expressed uncertainty as to their origin.

The report of a beach containing pebbles encrusted by serpulids, at 4–5 m above high-water mark (FN; M: 18; V: 141) is particularly interesting as such a beach has to record a stand of the sea, such encrustations normally being found in shallow water with a pebbly bottom. Regrettably, its locality has not been firmly established. It was "on the shore of Ralph Bay" (V:141) and was near a creek — the creek being *only separated from a larger expanse of water by a low strip of land* (M: 18). Darwin (*loc. cit.*) regarded it as an occurrence *of no value* in the context of evidence of uplift. Possibilities include (a) a low bank on the west side of Clarence Plains Rivulet, just upstream from the Droughty Point Road, (b) beside a small stream flowing into the Bay near the southern end of Huxleys Beach, (c) the rise at the south end of Gorringes Beach (fig. 6) and (d) near Calverts Lagoon. The first two are more probable, as there is deeper water immediately off-shore, a more likely environment for serpulids than Gorringes Beach, and Calverts Lagoon is not strictly on the shores of Ralphs Bay. Interbedded shingle and shell beds occur in an erosional cut at the back of Huxleys Beach, and dip south. Shingles and shells occur together on a vegetated bench at about 4.5 m above high-water mark just south of the small creek at Huxleys Beach.

Shells were reported at 60–80 ft (18–24 m) in the Government Domain (FN: X11) associated with round pebbles. A pebble horizon at about 18 m a.s.l. can be found south of Cornelian Bay and at Selfs Point to the north. If the shells were part of a shell bed deposited during a high sea-level, a bench due to marine erosion at this level might be expected. A bench occurs at just above 30 m a.s.l. at Government House and extends a little to the northwest to just above the entrance to the Royal Botanical Gardens. Another bench occurs at just above 20 m a.s.l. at the Cenotaph and at Selfs Point. It is interesting to note that Kerrison & Binns (1984: fig. 1) showed a shell midden at about 35 m a.s.l. topographically just above the Botanical Gardens, and another at about 25 m just inside the entrance to the Gardens. Darwin, apparently in some doubt as to the origin of the shell beds he saw, wrote (FN) *much to be said on both sides.* In a comment without further explanation, Darwin wrote *Water is said to be retiring — Earthquakes?* (FN: 3).

In an uncheckable comment, Wintle (1864a) reported extensive deposits of comminuted shells, all of recent species, for miles along the banks of the Derwent River, some at elevations of up to 100 ft [30 m] a.s.l. and from 50–100 yards [45–90 m] from the water's edge. In a further report (Wintle 1864b) he noted a cliff section ("part of the river-bank at Sandy Bay") including two shell beds separated by "a stratum of large rounded pebbles of the adjacent felspathic trap and greenstone with ... sandstone", the lower shell bed on a thin stratum of marl on the "equivalent to the English New Red Sandstone". The exposure was probably at the southern end of Long Beach or it may have been near St Stephens Church.

Shell beds are now known to occur around Ralphs Bay close to modern sea-level at many places, up to about a metre above sea-level at Richardsons, Huxleys and Gorringes Beaches, up to about 18 m a.s.l. at Dixon Point, Maria Point and on the hill south of Gorringes Beach and at 29 m north of Maria Point. All of these localities are on the eastern shore of the Bay south of the Neck. At Mary Anne Bay on the western shore south of Gellibrand Point at the southern entrance to Ralphs Bay, a shell bed at 24 m a.s.l. has been dated at 125 000 years BP and shows uplift of the area since the Last Interglacial Stage of about 18 m relative to the rest of eastern Australia (Murray-Wallace & Goede 1991).

In *Volcanic Islands ...* Darwin settled for the view that there had been "a small elevation of the land".

Subsidence

Darwin noted only two points indicating possible subsidence of the land. In FN: 2 and 3, he reported *deep water in Coves ... & soundings in channel* as suggesting the possibility of subsidence.

Earthquakes

In three places (FN: 3, 5 and XII), Darwin invoked earthquakes to explain phenomena that he observed. In the oldest of these phenomena, the occurrence of fragments of white siltstone in the Tertiary beds at Long Beach, his explanation was probably correct. No published comment was made by geologists on the influence of seismic activity on Tertiary sedimentation in Tasmania until those of Carey (1947) and Hills & Carey (1947). Application of the concept to the sediments at Sandy Bay was not published until 1955 (Spry). Darwin also invoked, with some doubt, the effect of earthquakes to account for *water said to be retiring.*

An earth tremor had been reported in Tasmania in 1827 (*Hobart Town Gazette,* 30 June) but it is unlikely that Darwin knew of it.

DARWIN AND FRANKLAND

The field notes reveal that Darwin gained considerable information about the general geology of VDL, acknowledged to have been from George Frankland, Surveyor-General. It included information on *Conical hills, Fossil shells* from the Launceston area, as well as geological observations on the centre of the island, the northwest, the northeast and the southwest. It seems from the field notes that it was ... *Mr. F*... (Frankland?) who was also able to tell him about the disappearance of oysters from the Derwent *within 2 years* (FN: X12), although in the *Geological Observations* ... (1844 edition: footnote to p. 141) the observation is attributed to "an intelligent farmer" and the date of disappearance given as 1834 (within two years of Darwin's visit).

Darwin may have walked about Hobart with Frankland on the 12th and certainly rode out with him on two occasions (the 13th and the 15th). From comments on Tasmanian geology (FN: 2) it is likely that Darwin had met him on or before the 7th. It is at least possible that Captain FitzRoy, as commander of an expedition with the prime function of measuring latitude and longitude, called upon or made contact with Frankland as Surveyor-General soon after the *Beagle* reached Sullivans Cove and may well have introduced Darwin to him. With Frankland, Darwin would have found a community of interests.

Frankland was born in Somerset, UK, in 1800, joined the army in 1819 and served in India (Eldershaw 1966: 410–411). He was appointed Surveyor-General in Poona in 1823 but later returned to England after taking leave in South Africa. Governor Arthur wrote to Earl Bathurst (Secretary of State) on 22 April 1826, asking for a mineralogist and civil engineer (HRA III, 5: 192). Unaware of this approach, Bathurst wrote to Arthur on 17 May 1826 (HRA,5: 233) instructing Arthur to appoint Frankland to "any of the appointments of a superior description to which he may be fitted as soon as possible". Three days later, Hay (Permanent Under-Secretary, Colonial Office) wrote to Arthur (*ibid.*: 234) appointing Frankland as Assistant Surveyor, pointing out that Frankland was an experienced surveyor as well as " being a person of Education and Science" and noting Bathurst's suggestion that Frankland might at the same time be employed in collecting "information in regard to Geology and Natural History".

Frankland arrived in VDL in July 1827 as Assistant Surveyor and was appointed Surveyor-General in March 1828. He participated in several major expeditions within the island and instructed his surveyors to take note of "every remarkable fact connected with the Natural History of the island". He also encouraged them to collect geological specimens and he maintained a museum which included geological specimens in the Surveyor-General's Office (Tasmanian State Archives, Outward Despatches 16: 270). Frankland was the Foundation Vice-President of the Van Diemen's Land Society, founded in 1830 for the "publication of local scientific information and foundation of a museum and botanic garden" (Robson 1983: 181). Darwin could have called upon Frankland's fund of knowledge so accumulated, and to a lesser extent upon reports of early expeditions such as those of D'Entrecasteaux and Flinders. From the Museum, Frankland gave Darwin fossil specimens (Banks 1971: 15), which included some that later received the attention of G.B. Sowerby in England (V, Appendix to Part 1 — Palaeozoic Shells from Van Diemen's Land) and became types of new species.

Darwin dined with Frankland twice, on the 12th and 15th, presumably at "Secheron", Battery Point, where Frankland lived with his wife and three children.

SUMMARY

Darwin's field notes record more fully than any other known sources his geological observations and thoughts while in Hobart Town and bring to light "new" observations. In so doing, they confirm that the site of collection of fossil bryozoa on which the genus *Stenopora* is based was the shoreline below Porter Hill, Lower Sandy Bay. They allow the routes of his "*pleasant little excursions*" to be more accurately traced and highlight some areas of present ignorance or uncertainty, namely the origin of the deposit of spring limestone above Burnett Street, Hobart; the localities of possibly uplifted shell beds and shingle with serpulids; and, from them, the presence and amount of uplift along the shores of the Derwent River.

The field notes would not receive a prize for spelling or ease of reading but they are useful as records of observations and deductions in the field. Darwin himself used them subsequently as the basis of the appropriate sections of published works, and they have been used by independent observers 150 years later, to pinpoint the localities of many of his observations.The observations were acute and as good as could be made at the time.

There is no doubt that Darwin took full advantage of the opportunities offered by his visit. He explored the geology (and zoology) of Hobart and its surrounds, as well as the countryside to the southeast, the south, the west and the north. He consulted and worked with the local "expert", George Frankland. He was active — he took only one day, a stormy Sabbath, off from his duties as a naturalist to write letters home. His observations ranged over many areas — geological, geomorphological, botanical, zoological, anthropological and social. He applied his considerable geological and zoological learning and experience acquired in Britain prior to his embarkation on the *Beagle* and during the voyage itself. His background allowed him to think imaginatively about what he saw.

ACKNOWLEDGEMENTS

During the preparation of this paper we received help and advice from Mr Alex Buchanan and Mr Bill Reid on aspects of the route followed by Darwin in his successful ascent of Mt Wellington (11 February 1836). Mr George Brown alerted us to the existence of a photograph of the lime quarry, formerly above the end of Burnett Street, West Hobart, visited by Darwin on 12 February, and Mr Lewis Woolley kindly permitted reproduction of the photograph taken by Charles A. Woolley in 1861. Mr Greg Manning, of OPTUS, allowed access to the former Crisp and Gunn Quarry in West Hobart for collection of a sample of a dyke rock which may have been relevant to the origin of the structure in the Burnett Street Quarry. In our attempts to reconstruct the route taken to Ralphs Bay by Darwin and George Frankland on 13 February, we received help from Dr Eric Guiler (sites of jetties), Mr Ted Bezzant and Mrs Audrey Hudspeth (possible localities for lime kilns in the Ralphs Bay area), and Mr Richard Lord (shell beds at

Lauderdale), from Mr Bill Reid (access to and information on early maps of the Ralphs Bay area), and Mr John Turner who guided us to a possible Darwin site at Huxleys Beach. We benefited from discussion of high-level shell beds with Dr Albert Goede. In the wider context Professor Frank and Mrs Jan Nicholas helped with comments and useful suggestions. Mrs Doris Banks helped with the transcription, checking reproduction of the manuscript notes, researching sources and editing of the text of this paper. Debbie Harding drew the maps accompanying this paper. The paper was improved by the editing of Mrs Alison Jones and setting by Ms June Pongratz. Our thanks are particularly due to Dr John Thorne for kindling anew our latent interests in Darwin's visit.

The Syndics of the Cambridge University Library kindly gave permission for use of the Field Notes, and Mr Adam Perkins of that Library provided information on the size of paper used by Darwin for his field notes. Miss Nino Strachey, Curator for Down House, provided information on the instruments used by Darwin, Ms Sheila A. Dean, of the Darwin Correspondence Project, Cambridge University Library, helped with information on the books available to Darwin on the *Beagle*, and Miss Tiffany Foster, Curator, Invertebrates and Plants Division, Department of Palaeontology, The Natural History Museum, London, provided information on the fossil plants collected in Hobart Town in the 1830s and 1840s and now in the collection of that Museum. Dr John Hunter, CSIRO, Hobart, helped with discussion of the tidal records in Hobart and directed our attention to Dr Bill Mitchell, Acting Director, National Tidal Facility, Flinders University, Adelaide, who was able to provide readily, the "predicted" tides in the Derwent River during Darwin's visit, information for which we were very grateful.

REFERENCES

ARMSTRONG, P., 1985: *CHARLES DARWIN IN WESTERN AUSTRALIA.* University of Western Australia Press, Perth.

BANKS, M.R., 1971: A Darwin manuscript on Hobart Town. *Pap. Proc. R. Soc. Tasm.* 105: 5–19.

BANKS, M.R. & HALE, G.E.A., 1958: A type section of the Permian System in the Hobart area. *Pap. Proc. R. Soc. Tasm.* 91 (1957): 41–64.

BANKS, M.R., COLHOUN, E.A. & HANNAN, D., 1987: Early discoveries of the effects of ice action in Australia. *J. Glaciol.* 33 (114): 231–235.

BURCKHARDT, F. & SMITH, S. (Eds), 1985: *THE CORRESPONDENCE OF CHARLES DARWIN.* Vols 1–5. Cambridge University Press.

CAREY, S.W., 1947: Geology of the Launceston district. *Rec. Q. Vict. Mus.* 2(1): 31–46.

COVINGTON, S., 1831–36: *JOURNAL.* Mitchell Library, Sydney, Manuscripts 2009/108. Item 5.

D'AUBISSON DE VOISIN, J.F., 1819: *TRAITÉ DE GEONOSIE.* Paris.

DARWIN, C.R., 1839a: *JOURNAL AND REMARKS* ... See under FitzRoy, R. 1939 (Vol. III).

DARWIN, C.R., 1839b: *JOURNAL OF RESEARCHES into the Natural History and Geology of the Countries visited during the voyage of H.M.S. Beagle round the World, under the command of Captain FitzRoy, R.N.* Henry Colburn, London; 2nd edn, corrected, with additions. John Murray, London. Published 1845 and later editions.

DARWIN, C.R.,1844: *GEOLOGICAL OBSERVATIONS on the volcanic islands visited during the voyage of H.M.S. Beagle, together with some brief notices of the geology of Australia and the Cape of Good Hope, being the second part of the geology of the voyage of the Beagle, under the command of Capt FitzRoy, R.N., during the years 1832–1836.* Smith, Elder and Company, London.
For Darwin's diary see Keynes, R.D., 1988, below.

DARWIN, C.R.,1846: *OBSERVATIONS ON SOUTH AMERICA.* Smith, Elder, London.

DAWSON, W., 1836 (or earlier): *MAP — MONMOUTH 26.* Department of Lands, Hobart

DESMOND, J. & MOORE, A., 1991: *DARWIN.* Michael Joseph, London.

DOTT, R.H., 1992: An introduction to the ups and downs of eustasy. *In* Dott, R.H. (Ed.): *EUSTACY: THE UPS AND DOWNS OF A MAJOR GEOLOGICAL CONCEPT. Mem. Geol. Soc. Amer.* 180: 1–16.

DUPERRY, L.I., 1830: VO*YAGE AUTOUR DU MONDE SUR LA CORVETTE, LA COQUILLE.* Bertrand, Paris.

ELDERSHAW, P.R., 1966: Frankland George (1800–1838). *In* Pike, D. (Ed.): *AUSTRALIAN DICTIONARY OF BIOGRAPHY*, Vol. 1 (1788–1850). Melbourne University Press: 410–411.

ETTINGSHAUSEN, C. VON, 1883: Beiträge zur Kenntniss der Tertiar flora Australiens. *Denksch. k. Akad. Wissensch. Wien.* Bd. XLVII: 48 pp., 7 plates.

FITZROY, R. (Ed.), 1839: *NARRATIVE OF THE SURVEYING VOYAGES of His Majesty's Ships* Adventure *and* Beagle *between the years 1826 and 1836, describing their examination of the southern shores of South America, and the* Beagle's *circumnavigation of the globe.* In three volumes, plus an Appendix to Volume II. Henry Colburn, London.
Volume II: *PROCEEDINGS OF THE SECOND EXPEDITION*, 1831–1836, under the command of Captain Robert FitzRoy, R.N.
Volume III: *JOURNAL AND REMARKS*, 1832–1836, by Charles Darwin.

FLINDERS, M.,1801: *OBSERVATIONS ON THE COASTS OF VAN DIEMEN'S LAND, on Bass's Strait and its islands and on part of the Coast of New South Wales, intended to accompany the charts of the late discoveries of those countries.*John Nichols, London.

FLINDERS, M., 1814: *A VOYAGE TO TERRA AUSTRALIS ... in the years 1801, 1802 and 1803, in His Majesty's Ship* The Investigator. 2 vols and atlas. G. and W. Nicol, London.

FRANKLAND, G., 1839: *MAP OF VAN DIEMEN'S LAND.* Cross, London.

GEIKIE, A., 1909: *CHARLES DARWIN AS A GEOLOGIST.* Cambridge University Press.

HEBERT, L., 1830: *MAP OF VAN DIEMEN'S LAND.* Issued by the Colonial Office, London. (In AOT Map Collection, NS 1/ 35/ 56 southeast section).

HERGT, J.M. & MCDOUGALL, I., 1989: Petrography in Jurassic Dolerite. *In* Burrett, C.F. & Martin, E.L. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ.* 15: 378–381.

HILLS, C.L. & CAREY, S.W., 1949: Geology and Mineral Industry. *In* Cerutty, L. (Ed.): *HANDBOOK FOR TASMANIA.* ANZAAS, Hobart: 21–44.

HUDSPETH, A., SCRIPPS, L. & MACFIE, P., 1994: *CLARENCE HISTORICAL SITES SURVEY. Parts 1 & II.* A report produced for the National Estate with assistance from the Clarence City Council. The Partners, Hobart.

JOHNSTON, R.M., 1882: Notes showing that the estuary of the Derwent was occupied by a fresh-water lake during the Tertiary Period. *Pap. Proc. R. Soc. Tasm.* (1881): 7–21.

JOHNSTON, R.M., 1888: *SYSTEMATIC ACCOUNT OF THE GEOLOGY OF TASMANIA.* Government Printer, Hobart.

JOHNSTONE, G.S., 1966: *THE GRAMPIAN HIGHLANDS.* 3rd edn. British Regional Geology. Her Majesty's Stationery Office.

JUDD, J.W., 1885: On the Tertiary and older peridotites of Scotland. *Q. J. Geol. Soc. Lond.* 41: 354–418, esp. 383–389).

JUKES, J.B., 1847: Notes on the Palaeozoic formations of New South Wales and Van Diemen's Land. *Q. J. Geol. Soc. Lond.* 3: 241–249.

KERRISON, A.R. & BINNS, M.A., 1984: A midden excavation — Royal Tasmanian Botanical Gardens, Hobart. *Pap. Proc. R. Soc. Tasm.* 118: 53–64.

KEYNES, R.D. (Ed.), 1988: *CHARLES DARWIN'S* BEAGLE *DIARY.* Cambridge University Press, Cambridge.

LEAMAN, D.E., 1972: *HOBART, TASMANIA.* Tas. Dep. Mines Geol. Atlas 1:50 000 Series. Sheet 82 (8312S).

LEAMAN, D.E., 1976: *HOBART, TASMANIA.* Tasm. Dep. Mines Geol. Atlas 1: 50 000 Series. Expl. Rep. Sheet 82 (8312S).

LEAMAN, D.E., 1997: Magnetic rocks — their effect on compass use and navigation in Tasmania. *Pap. Proc. R. Soc. Tasm.* 131: 73–77.

LEAMAN, D.E., 1999: The nature of jointing, Tasman Peninsula, southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 133(1): 65–76.

LORD, G.M., 1998: *SANDY BAY; A HISTORY OF THE GOLF LINKS DISTRICT.* Richard Lord and Partners, Taroona.

LYELL, C., 1830–33: *PRINCIPLES OF GEOLOGY, being an attempt to explain the former changes of the Earth's surface by causes now in operation.* 3 vols. John Murray, London. With later editions.

M'CORMACK, R., 1847: Geology of Tasmania. *Ross's voyage of discovery and research in the Southern and Antarctic regions.* Vol. 2, appendix 1: 391–400.

MACCULLOCH, J., 1821: *A GEOLOGICAL CLASSIFICATION OF ROCKS, with descriptive synopses, comprising the elements of practical geology.* Longman, Hurst, Rees, Orme and Brown, London.

MILLIGAN, J., 1849: On some fossil plants found near Hobart Town and Launceston. *Tasm. J. Nat. Sci.* 3: 131–139.

MILLIGAN, J.,1854: Monthly notices for 9 November, 1853. *Pap. Proc. R. Soc. Van Diemen's Land* 2 (1852–54): 516.

MURRAY-WALLACE, C.V. & GOEDE, A., 1991: Aminostratigraphy and electron spin resonance studies of late Quaternary sea level changes and coastal neotectonics in Tasmania, Australia. *Z. Geomorph. N. F.* 35(2): 129–149.

NICHOLAS, F. W. & NICHOLAS, J.M., 1989: *CHARLES DARWIN IN AUSTRALIA.* Cambridge University Press.

NICHOLLS, M. (Ed.), 1977: *THE DIARY OF THE REVEREND ROBERT KNOPWOOD.* Tasmanian Historical Research Association.

OLDROYD, D., 1996: *THINKING ABOUT THE EARTH; A HISTORY OF IDEAS IN GEOLOGY.*Harvard University Press, Cambridge, Mass.

PÉRON, F., 1807: *VOYAGE DE DÉCOUVERTES AUX TERRES AUSTRALES, exécuté par ordre de sa Majesté l'Empereur et Roi, sur les corvettes* Le Géographe, Le Naturaliste *et la goélette* La Casuarina, *pendant les années 1800, 1801, 1802, 1803 et 1804, rédigé par M.F. Péron.* Imperial Press, Paris. A second volume was completed by L. Freycinet, in 1816.

QUINCEY, E. DE, 1987: *THE HISTORY OF MT WELLINGTON.* Printed by *The Mercury,* Hobart.

RAMSAY, A.C., 1852: On the superficial accumulation and surface markings of North Wales. *Q. J. Geol. Soc.* 8: 371–376.

RAMSAY, A.C.,1855: On the occurrence of angular, subangular, polished and striated fragments and boulders in the Permian breccia of Shropshire, Worcestershire & c. *Q. J. Geol.Soc.* 11: 185–205.

ROBSON, L., 1983: *A HISTORY OF TASMANIA. Vol. 1.* Oxford University Press, Melbourne.

SCOTT, T.H., 1824: Sketch of the geology of New South Wales and Van Diemen's Land. *Ann. Phil.* 7: 462.

SPRY, A.H., 1955: The Tertiary volcanic rocks of Lower Sandy Bay, Hobart. *Pap. Proc. R. Soc. Tasm.* 89: 153–168.

STEVENSON, P.C., 1971: Site investigation at Wrest Point, Sandy Bay. *Tasm. Dep. Mines Tech. Rep.* 14: 115–117.

STRZELECKI, P.E. VON, 1845: *PHYSICAL DESCRIPTION OF NEW SOUTH WALES AND VAN DIEMEN'S LAND.* Longman, Brown, Green and Longmans, London.

SUTHERLAND, F.L. & WELLMAN, P., 1986: Potassium-argon ages of Tertiary volcanic rocks, Tasmania. *Pap. Proc. R. Soc. Tasm.* 120: 77-86.

TWELVETREES, W.H. & PETTERD, W.F., 1900: On the Mesozoic dolerite and diabase in Tasmania. *Pap. Proc. R. Soc. Tasm.* (1898–99): lxvii, 47–55.

WINTLE, S.H., 1864a: A sketch of the principal geological features of Hobart, Tasmania. *Q. J. Geol. Soc.* 20: 465–469.

WINTLE, S.H.,1864b: Evidences of the shell deposits seen around this city , not being produced by the aborigines, and the period of their origin being post Tertiary. *Pap. Proc. R. Soc. Tasm.* Monthly Notices for (April): 32.

(accepted 5 July 1999)

ELEPHANT SEAL OIL CARGOES FROM KING ISLAND, BASS STRAIT, 1802–1819: WITH ESTIMATES OF NUMBERS KILLED AND SIZE OF THE ORIGINAL POPULATION

by John K. Ling

(with one table, one text-figure, one plate and an appendix)

LING, J.K., 1999 (31:x): Elephant seal oil cargoes from King Island, Bass Strait, 1802–1819: with estimates of numbers killed and size of the original population. *Pap. Proc. R. Soc. Tasm.* 133(1): 51–56. ISSN 0080-4703. PO Box 271, Clare, Australia 5453.

Southern elephant seals (*Mirounga leonina*) were harvested for their oil at King Island, Bass Strait, from 1802 to 1819, by which time they were virtually extinct at that location and have not returned since. Oil cargo statistics have been collated from various secondary sources; in arriving at annual yields, allowance was made for untallied (unquantified) cargoes and a certain amount of waste and onsite use. Depending on the methods of calculation, between 920 and 1326 tons of oil were produced, almost 75% of this in the first three years and 95% by 1807. Some 10 000 adult and sub-adult elephant seals would have had to be slaughtered to generate such yields. The approximate total size of the pristine populations is believed to have been between about 10 000 and 17 000, based on the various calculated oil yields and a number of fairly broad assumptions.

Key Words: elephant seal oil, King Island, Bass Strait, population size, nineteenth century.

INTRODUCTION

King Island (40°S,144°E) lies at the western end of Bass Strait off the northwestern tip of Tasmania. In October 1801, Governor King, after whom the island was named, instructed Lieutenant James Grant of H.M. Brig *Lady Nelson* to carry out, *inter alia*, a survey of the recently discovered island. Grant named a bay on the island the Bay of Elephants (now Sea Elephant Bay), because of the large numbers of sea elephants (southern elephant seals, *Mirounga leonina*) present on the beaches at that time (Cumpston 1973).

Sealing gangs were quickly dispatched from Sydney to harvest elephant seals for their oil, and fur seals (*Arctocephalus* spp.) and, to a lesser extent, sea lions (*Neophoca cinerea*) for their pelts and oil. Cumpston (1973) wrote an excellent account of the early history of the seal oil industry at King Island. Péron, who was the zoologist on Baudin's 1800–1804 expedition, also described (1816, in Micco 1971) with accompanying illustrations (pl. 1) the elephant seal industry on King Island, which Baudin visited in December 1802. At this time, most breeding adult elephant seals would have left the island, and only new-born pups and moulting immature seals would have occupied the beaches, if the same annual cycle were followed as that described by Carrick *et al.* (1962b) for Macquarie Island. Péron, however, stated the seals were from 8–10 m in length, so he must have seen very big males, despite the fact that, in view of what we know now (Laws 1953), it would be very unlikely for the largest to have exceeded 6 m in length.

In the early 19th century, elephant seal oil was regarded as being only slightly inferior to oil of the sperm whale (*Physeter macrocephalus*). These natural oils were used for illumination — "burning in a bright pure flame without smell or smoke" (Steven 1978) — for lubricating machinery, dressing harness and other leather goods, and ropemaking, and in the manufacture of certain cloths. Seal oil fetched up to £20 a ton on the London market; therefore, it was an important contributor to Australia's early export income.

It is possible, although no records have been seen, that British and American whaling ships may also have harvested southern elephant seals to supplement their whale oil cargoes, which were taken directly to their home ports. This account deals only with the colonial industry at King Island.

Southern elephant seals no longer exist on King Island, although stragglers have been reported in Tasmanian, Bass Strait and South Australian waters (Warneke 1982). No other breeding colonies are known to have existed on mainland or Tasmanian coasts or islands. We shall probably never know precisely how many lived and bred on King Island before they were discovered. We can, however, gain some idea of the numbers harvested from the extensive store of information that exists in libraries around the world in the form of shipping records, logs, cargo manifests and newspaper articles of the time; these include numerous references to elephant seal harvests and oil cargoes. Such sources have been searched meticulously by many maritime historians — most notably Cumpston (1968, 1973, 1977), Fowler (1980) and Nicholson (1983) — in the course of compiling their various historical accounts, which have been used for the purpose of this study.

Hindell & Burton (1988) have already made a very thorough assessment of elephant seal oil harvests at Macquarie Island in the 19th and early 20th centuries, also using only secondary sources of data. They developed a model for quantifying the original elephant seal population on Macquarie Island, by applying modern population parameters, emanating from intensive studies there over many years, to the early harvest figures. No such analysis of the King Island elephant seal oil industry appears to have been attempted; nor will it be here. However, it is possible to derive annual and total oil yields from the secondary sources cited above and make some estimates of how many elephant seals may have supported this industry.

METHODS

Details of vessel departure and return dates, ports of call and seal product cargoes procured at King Island between 1802 and 1819 were extracted from several secondary sources cited above (appendix 1). Data from each literature source were then collated year by year and, finally, the figures were consolidated into annual and total yields. However, a number

PLATE 1
Engraving by Charles Lesueur of Sea Elephant Bay, King Island, in December 1802, showing the camp of the Baudin expedition scientists, elephant seals, members of a sealing gang on the beach and a whale boat in the surf. Museum d'Historic Naturelle, Le Havre, No. 80007.

of complicating factors in the oil cargo records appeared in various sources consulted during this study; namely:
(1) Cargoes were reported as "elephant oil" (from elephant seals), "seal oil" (from fur seals and sea lions) and simply "oil" (with no indication as to species — and the source will not always help). It is possible that some oil emanating from King Island came from fur seals and sea lions, since oil from these species certainly was obtained at islands in eastern Bass Strait, where elephant seals did not occur. As the last fur seal skins were taken at King Island in 1807 (Ling 1999), any oil shipments after that date may be deemed to have come from elephant seals.
(2) The sealing season tended to be concentrated in the austral summer months when the elephant seals were ashore at varying times according to age and sex (Carrick *et al.* 1962b). Therefore, harvesting may have occurred at the end of one year or the beginning of the next. Moreover, some cargoes were shipped months or even years after the oil had been extracted; so again, the times of harvesting are not known precisely.
(3) The terms "Bass Strait" and "Bass's Strait" are used frequently. The latter term sometimes appeared in parentheses after "King(s) Island", but not always, so as to be regarded as a reliable alternative name for King Island. Therefore, only oil stated as having come from King Island is considered here.
(4) Vessels from Sydney visiting King Island often stopped off at islands in eastern Bass Strait on the outward or inward voyage or both. Hence, the exact source or sources of seal products, including oil, is not always clear.
(5) With the presence of both British and American ships in the southwestern Pacific — principally hunting whales — imperial and American units of oil measurement may well have been used interchangeably.
(6) Oil cargoes were sometimes expressed as "small quantity" or, simply "oil". It is possible that only small quantities were involved, and more exact tonnages were given for bigger amounts.

Tallied (quantified) cargoes were expressed in several different units of measurement in the literature sources; namely:
Ton/tun — a large barrel, cask or hogshead holding 252 old wine gallons. Four Bordeaux wine casks occupied one ton (= 32 ft^3) of shipping space and held 2016 English pounds weight of 15 ounces to the pound; equal in weight of water to 2000 pounds (Cumpston 1968).
Cask — a wooden barrel of no fixed size; but commonly varying from 42 to 50 gallons capacity. Thus six casks of 42 imperial gallons equalled one ton. (Incidentally, 50 American gallons equal 42 imperial gallons.)
Tierce — a small barrel holding 12 gallons.
Butt — a large barrel holding 96 gallons.

A cask will, for the purpose of this study, be deemed to have contained 42 imperial gallons and a ton to consist of 252 gallons and, since all oil would have been shipped in casks, all cargoes have been converted to tons.

Untallied (unquantified) cargoes were calculated as the average in any one year, or, in the case of the year 1807, when no other cargoes were listed, as the average of all tallied cargoes, including and excluding the two largest cargoes of 300 tons and 90 tons. This gave rise to "minimum" and "maximum" figures discussed below. A "small quantity" was arbitrarily deemed to be one-tenth of an untallied cargo in a particular year.

Since some oil was used on the island by the sealers for heating, cooking and illumination, and there was doubtless a certain amount of wastage, total figures have been increased by 5% (following Hindell & Burton 1988).

RESULTS AND DISCUSSION

The exploitation of southern elephant seals at King Island was a short-lived affair, lasting only from 1802 to 1819, with no cargoes being reported for 1808 and 1813 to 1817 (inclusive) in the sources consulted in this study. It is estimated that between 920 tons (tallied) and 1326 tons of oil (tallied plus untallied) were procured during those years, of which about 75% was obtained in the first three years and 95% by 1807. However, because of the difficulties discussed in the Methods section above, it is possible to derive several different total yields of oil.

The very first cargo listed in appendix 1 was 500 gallons (2 tons), but Cumpston (1973: 46) stated that blubber and oil were obtained from 600 elephant seals between February and May 1802, when predominantly sub-adult and adult males would probably have been ashore moulting. He also stated (1973: 46) that one elephant seal (presumably a large male) gave one ton of oil or approximately 250 gallons; elsewhere (1968: 52) he stated that a male elephant seal will yield a third to half a ton (80 to 125 gallons). Hindell & Burton (1988) used figures of 0.2 and 0.07 tons (50 and 17.6 gallons) of oil per male and female respectively, and their figures will be used here. Thus 600 males would have yielded 120 tons of oil and 600 females, 42 tons, with the likely amount being about 100 tons, given the preponderance of large males present at that time.

Two very large shipments of 300 tons in 1803 and 90 tons in 1804 would have increased the averages for the purpose of calculating untallied cargoes in those years; so two sets of figures were derived; one set included these amounts and the other excluded them from the calculations. Taking the above factors into account, the total calculated amount of elephant seal oil shipped from King Island between 1802 and 1819 varied between 920 and 1326 tons, as follows:

920 tons: based only on tallied cargoes listed in appendix 1, plus the 5% wastage factor;

1081 tons: based on only 500 gallons (2 tons) being landed in May 1802, and untallied cargoes in 1803, 1804 and 1807 being calculated with the 300 and 90 tons of 1803 and 1804, respectively, being excluded, plus the 5% wastage factor;

1326 tons: based on 600 elephant seals giving 100 tons of oil (see text above) landed in May 1802 and averages for untallied cargoes being calculated with the inclusion of the 300 and 90 tons of 1803 and 1804, respectively, plus the 5% wastage factor.

Figure 1 depicts annual "minimum" and "maximum" oil production, based on tallied and untallied cargoes listed in appendix 1, plus the 5% wastage factor. The "small quantity" listed for 1804 was arbitrarily taken to be one-tenth of the two other untallied cargoes for that year.

Reported exports of elephant seal oil from King Island to England between 1803 and 1807 amounted to only 448 tons. There are no explanations as to what happened to the remaining quantities of oil, but much of it could have been consumed by the New South Wales colony. There is also no explanation of the source or time of harvesting of 150 tons stated by Fowler (1980) to have been exported in April 1807. In the absence of any explanation, it is assumed that this oil had been obtained and held in storage pending shipment; it is therefore included somewhere in the yearly figures other than 1807.

The dramatic decline in oil production after 1805 suggests that the elephant seals had already become scarce, through either being depleted in numbers or having been scared away. It is likely that every available large breeding or non-breeding seal, and possibly every available seal of any size, was taken.

If *only* breeding adult elephant seals were taken and the sex ratio at King Island was the same as that proposed for Macquarie Island by Carrick & Ingham (1962b), namely one male to 12 females, and the average oil yield per seal is known, it is possible to convert oil tonnages to seals.

Thus $T = M \times 0.2 + F \times 0.07$

where T = tonnage of oil

M = number of breeding males

F = number of breeding females

if $F = 12M$

$T = M \times 0.2 + 12M \times 0.07$

$= 1.04M$

therefore $M = T/1.04$

$F = 12T/1.04$

As table 1 — based on the above calculations — shows, 1149 males and 12 168 females would be required to produce 1081 tons of oil, and 1800 males and 13 800 females to yield 1326 tons.

However, it is most likely that significant quantities of oil were also obtained from large immature elephant seals — if not from any seals that were available at the time. Immature males, aged between four and seven years, increase in length by about 60% and in weight by about four times, compared with females whose growth flattens out at four years (Carrick *et al.* 1962a, Ling & Bryden 1981). Thus, large immature males would certainly have been killed if and when they were present, as they would have been in midsummer. If it were possible to know exactly when each lot of oil was obtained, a knowledge of the southern elephant seal's annual cycle might give some idea of what age or sex group was being exploited at any particular time. Since even the dates of shipment often bore little relationship to when the oil was obtained, it is not possible to guess what category of seals may have contributed to each cargo and, thereby, convert oil quantities to numbers of seals of a particular size.

There is also little information in the literature to indicate the original size of the elephant seal population on King Island. Péron (1816, in Micco 1971: 11) stated that

> All the shores of the island are covered with a prodigious number of amphibians, some of which are not less than eight to ten metres long...

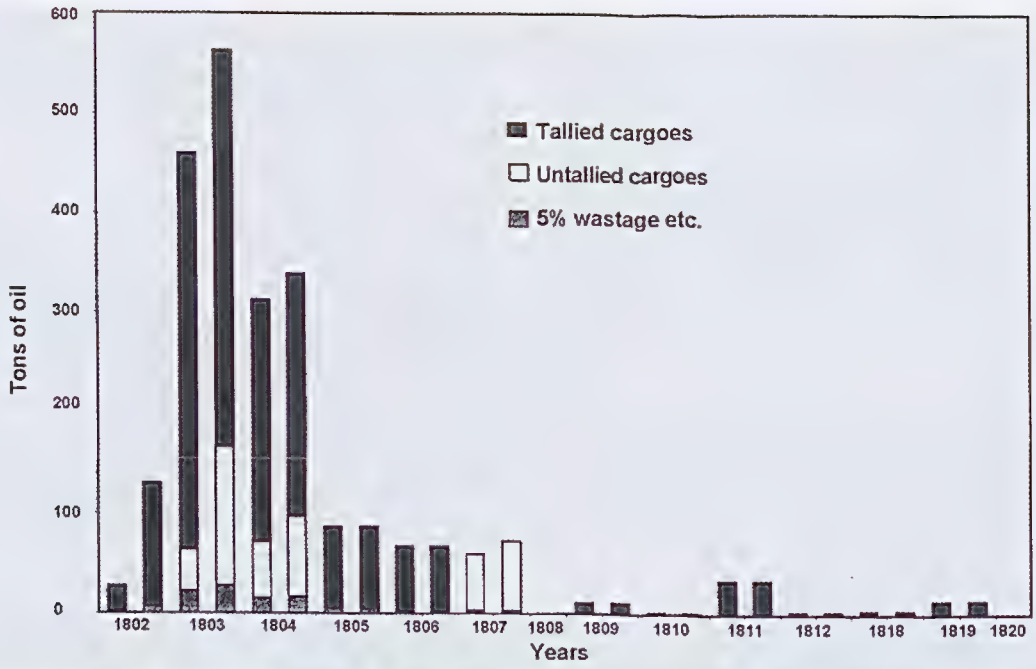


FIG.1 — Minimum (left-hand columns) and maximum (right-hand columns) annual cargoes of elephant seal oil shipped from King Island, 1802–1819; years 1813–1817 omitted (see text for further explanation).

Péron was at King Island from 6–27 December 1802, when mostly immature elephant seals, including quite large (3–4 m) males, would have hauled out to moult (Ling & Bryden 1981). Some estimate of the total size of the population may be made from notional numbers of breeding males and females that might have been harvested in 1803 to yield 460 and 563 tons of oil — the lower and higher figures as discussed above (table 1). That is

460 tons = 442 breeding males + 5304 breeding females
= 5746

563 tons = 541 breeding males + 6492 breeding females
= 7033

Carrick & Ingham (1962b) arrived at a population of 110 000 elephant seals, including pups, at Macquarie Island, based on figures of 36 000 adult females and 3500 adult males, which works out to a multiplier factor of 2.78. Applying this factor to the 1803 figures gives a total population at that time of between 15 974 and 19 552 It is extremely unlikely, however, that only breeding adults would have been taken; therefore the actual numbers of these age/sex categories would have been less, with an unknown number of immature and sub-adult seals (particularly males) also contributing. Furthermore, as there would probably have been some breeding between 1802 and 1807 — although the population had been severely depleted — three- and four-year-old males would have been available for slaughter. These and sub-adult males would have produced almost as much oil (0.2 ton) as a breeding bull; i.e. three times the amount obtainable from an adult female. Thus the total number of breeding adults killed may have been less by a third to a half than the above figures (table 1) suggest, say 6000 to 8000; the total number of seals of all sizes and both sexes killed may have been around 10 000. If, however, as many sub-adult males as breeding males were killed in 1803, the production figures then become:

460 tons = 884 males + 4043 breeding females = 4927
563 tons = 1082 males + 4957 breeding females = 6039

Application of the 2.78 multiplier factor gives a total population in 1803 of between 13 697 and 16 788 elephant seals. A more accurate figure may be possible using an analysis of catch statistics, measures of effort and modern population parameters that are beyond the scope of this paper.

Hindell & Burton (1988) used a much more sophisticated model to estimate the size of the original elephant seal population at Macquarie Island, from where 8380 tons of oil had been removed. They arrived at a figure of between 93 000 and 110 000 animals, which equates to about 11 to 13 seals of all categories per ton of oil. Applying the same factors to the minimum and maximum oil yields from King Island (920 and 1326 tons) suggests a pristine population there ranging from 10 120 to 11 960 and 14 506 to 17 238 seals, respectively.

It is clear that elephant seal oil production on King Island declined dramatically after 1804 and had almost ended by 1807. The population had either been decimated or most of the survivors, particularly breeding animals, had fled. By 1820, elephant seals were virtually if not actually extinct on the island. Carrick and Ingham (1962a) stated that they had been exterminated in the early part of the 19th century.

In 1820, the British Government duty on oil from the colonies was lifted, and it would be surprising indeed if elephant seals were not hunted at King Island for their oil, if they were still there, at least in conjunction with the burgeoning whaling industry. Moreover, draft legislation aimed at liberalising the importation of seal products into Great Britain was to have gone into effect from 1 March 1807 (Steven 1978). Surely, if elephant seals were still present on King Island even at that time, the industry would have continued to prosper until whaling reached its zenith in the 1830s.

TABLE 1
Notional numbers of adult male and female elephant seals required to produce minimum and maximum annual yields of oil*

	Minimum Yields			Maximum Yields		
Year	Tons of oil	Males	Females	Tons of oil	Males	Females
1802	27	135	†(1620)	130	650	†(7800)
1803	460	442	5304	563	541	6492
1804	313	301	3612	339	326	3912
1805	87	84	1008	87	84	1008
1806	67	64	768	67	64	768
1807	59	57	684	72	69	828
1808						
1809	11	11	132	11	11	132
1810	2	2	24	2	2	24
1811	34	33	396	34	33	396
1812	3	3	36	3	3	36
1813						
1814						
1815						
1816						
1817						
1818	4	4	48	4	4	48
1819	14	13	156	14	13	156
Total	1081	1149	12 168	1326	1800	13 800

* See text for further explanation.
† Equivalent number of breeding females if only adult males contributed the oil in the first year.

ACKNOWLEDGEMENTS

I thank Mark Hindell and Michael Bryden for their helpful comments on earlier drafts of this manuscript, and my wife, Pauline, for typing it. Figure 1 was prepared by Joanne Goodwin, and plate 1 was kindly provided by Mme Jacqueline Bonnemains, Curator of the Lesueur Collection of the Museum of Natural History in Le Havre, France. The helpful comments of two anonymous referees are also gratefully acknowledged.

REFERENCES

CARRICK, R. & INGHAM, S.E., 1962a: Studies of the southern elephant seal, *Mirounga leonina* (L.). I. Introduction to the series. *CSIRO Wildl. Res.* 7(2): 89–101.

CARRICK, R. & INGHAM, S.E., 1962b: Studies of the southern elephant seal, *Mirounga leonina* (L.). V. Population dynamics and utilization. *CSIRO Wildl. Res.* 7(2): 198–206.

CARRICK, R., CSORDAS, S.E. & INGHAM, S.E., 1962a: Studies of the southern elephant seal, *Mirounga leonina* (L.). IV. Breeding and development. *CSIRO Wildl. Res.* 7(2): 161–197.

CARRICK, R., CSORDAS, S.E. & INGHAM, S.E., KEITH, K., 1962b: Studies of the southern elephant seal, *Mirounga leonina* (L.). III. The annual cycle in relation to age and sex. *CSIRO Wildl. Res.* 7(2): 119–160.

CUMPSTON, J.S., 1968: Macquarie Island. *ANARE Sci. Rep.*, Ser. A(1) 93: 1–380.

CUMPSTON, J.S., 1973: *FIRST VISITORS TO BASS STRAIT.* Roebuck, Canberra.

CUMPSTON, J.S., 1977: *SHIPPING ARRIVALS AND DEPARTURES, SYDNEY, 1788–1825.* Roebuck, Canberra.

FOWLER, R.M., 1980: *THE FURNEAUX GROUP, BASS STRAIT. A HISTORY. Vol. 1.* Roebuck, Canberra.

HINDELL, M.A. & BURTON, H.R., 1988: The history of the elephant seal industry at Macquarie Island and an estimate of the pre-sealing numbers. *Pap. Proc. R. Soc. Tasm.* 122(1): 159–176.

LAWS, R.M., 1953: The elephant seal (*Mirounga leonina* Linn.) I. Growth and age. *Falk. Is. Dep. Surv. Sci. Reps* 8: 1–62.

LING, J.K., 1999: Historical harvests of fur seals and sea lions from Australia, New Zealand and adjacent subantarctic islands. *Aust. Zool.* (in press).

LING, J.K. & BRYDEN, M.M., 1981: Southern elephant seal *Mirounga leonina* Linnaeus 1758. *In* Ridgway, S.H. & Harrison R.J. (Eds): *HANDBOOK OF MARINE MAMMALS, Vol. 2.* Academic Press, London: 297-327.

MICCO, H.M., 1971: *KING ISLAND AND THE SEALING TRADE 1802.* A translation of Chapters XXII and XXIII of the narrative by Francois Péron published in the official account of the VOYAGE OF DISCOVERY TO THE SOUTHERN LANDS undertaken in the Corvettes *Le Geographe*, *Le Naturaliste* and the schooner *Casuarina*, during the years 1800 to 1804, under the command of Captain Nicolas Baudin (1816). Roebuck, Canberra.

NICHOLSON, I.H., 1983: *SHIPPING ARRIVALS AND DEPARTURES, TASMANIA. Vol. 1. 1803–1833.* Roebuck, Canberra.

STEVEN, M.J.E., 1978: Exports other than wool. *In* Abbott, G.J. & Nairn, N.B. (Eds): *ECONOMIC GROWTH OF AUSTRALIA 1788-1821.* Melbourne University Press, Melbourne: 285–305

WARNECKE, R.M., 1982: The distribution and abundance of seals in the Australasian region, with summaries of biology and current research. *MAMMALS IN THE SEAS. Vol. 4. FAO Fish. Ser. 5.* FAO, Rome: 431–475.

(accepted 5 July 1999)

APPENDIX 1
Details of elephant seal oil cargoes obtained at King Island: 1802–1819

Vessel	Departure Date	Departure Port	Arrival Date	Return Date	Return Port	Arrival Date	Cargo*/ Remarks
Harrington	20.2.1802	Sydney	2.3.1802	27.5.1802	Sydney	31.5.1802	500 gallons (2 or 100 tons)†
Margaret	5.6.1802	Sydney	?	8.7.1802	Norfolk Island	?.8.1802	6000 gallons obtained (24 tons)
John	16.6.1803	Sydney	?.7.1803	12.8.1803	Sydney	5.9.1803	14 tons
Surprise	31.31803	Sydney	?	12.8.1803	Sydney	26.8.1803	700 gallons (2.8 tons)
Governor King	10.61803	Sydney	?	3.8.1803	Sydney	23.8.1803	21 butts = 2016 gallons (8 tons)
John	17.91803	Sydney	?	?	Sydney	26.12.1803	"oil" (66/19 tons, max/min)
Governor King	4.91803	Sydney	?	?	Sydney	16.10.1803	35 tons
Endeavour	18.11.1803	Sydney	?	?	Sydney	17.1.1804	"small quantity" (6/2 tons, max/min)
Edwin	20.10.1803	Sydney	?	?	Sydney	26.11.1803	"oil" (66/19 tons, max/min)
Governor King	25.10.1803	Sydney	?	?	Sydney	26.12.1803	37 tons
Charles	?1803		?	?	?USA	?	300 tons
Governor King	7.1.1804	Sydney	?	?	Sydney	7.2.1804	39 tons
Governor King	5.4.1804	Sydney	?	?	Sydney	16.6.1804	30 tons
Scorpion	?	Sydney	?	?	Sydney	15.9.1804	90 tons‡
Governor King	?	Sydney	?	?	Sydney	2.10.1804	33 tons
Endeavour	15.9.1804	Sydney	?	?	Sydney	30.10.1804	15 tons
Nancy	?	Sydney	?	?	Sydney	14.8.1804	"oil"
Nancy	26.8.1804	Sydney	?	?	Sydney	19.10.1804	15 tons (27/19 tons, max/min)
Nancy	6.11.1804	Sydney	?	?	Sydney	19.12.1804	"oil" (+skins) (27/19 tons, max/min)
Edwin	?.12.1803	Sydney	?	27.1.1804	Sydney	8.2.1804	"oil" (+ skins) (27/19 tons, max/min)
George	?	Sydney	?	8.2.1804	Sydney	15.2.1804	6 tons (8 tons)§
Good Intent	?	Sydney	?	?	Sydney	15.3.1804	2.5 tons of "oil" (+ skins)
George	?	Sydney	?	?	Sydney	29.5.1804	9 tons
George	15.2.1805	Sydney	?	?	Sydney	17.5.1804	6 tons (8 tons)
Endeavour	?	Sydney	?	?	Sydney	16.5.1804	13 tons
Endeavour	29.6.1805	Sydney	?	?	Sydney	22.10.1804	14 tons (+16 tons left behind)
Governor King	?	Sydney	?	?	Sydney	13.3.1804	34 tons
Sophia	?	Sydney	?	?	Port Dalrymple	18.3.1804	64 tons
Marcia	?	Port Dalrymple	?	?	Sydney	14.2.1807	"oil" (+ skins) (28 tons)
Governor Hunter	?	Sydney	?	?	Port Dalrymple	23.5 1807	"oil" (+ skins) (28 tons)
Marcia	?	Sydney	?	?	Sydney	19.3.1809	10 tons
Endeavour	?	Sydney	?	?	Sydney	3.4.1810	2 tons of "oil"
Northumberland	?	Sydney	?	?	Sydney	4.3.1811	18 tons
King George	6.2.1811	Hobart	?	?	Sydney	23.2.1811	14 tons
Brothers	?	Port Dalrymple	?	?	Sydney	1.4.1812	3 tons
Endeavour	?	King Island	?	?	Sydney	10.4.1818	4 tons
Endeavour	?	King Island	?	?	Sydney	9.1.1819	13 tons

Compiled from Cumpston (1973, 1974, 1977), Fowler (1980), Nicholson (1983) and Steven (1978).

* Originating from King Island, but not always specified in texts as elephant seal oil. Figures in parenthesis are the calculated tonnages for untallied cargoes.

† Cumpston (1973: 46) stated that blubber and oil were from 600 elephant seals, but only 500 gallons (2 tons) were delivered to Sydney.

‡ Stated by Cumpston (1973: 85) to be 94 tons.

§ Cumpston (1973: 82) stated that the *George* was shortly to be expected with 2000 gallons (8 tons) of oil, but (p.84) that only 6 tons had been loaded on 8 February. The larger figure (= 8 tons) has been used in any calculations.

HABITAT ASSOCIATIONS AND NATURAL HISTORY OF THE TASMANIAN "SNOW SKINKS" (*NIVEOSCINCUS* SPP.)

by Jane Melville and Roy Swain

(with two tables and four text-figures)

MELVILLE, J. & SWAIN, R., 1999 (31:x): Habitat associations and natural history of the Tasmanian "snow skinks" (*Niveoscincus* spp.). *Pap. Proc. R. Soc. Tasm.* 133(1): 57–64. ISSN 0080-4703. Formerly School of Zoology, University of Tasmania, now Department of Biology, Washington University, Campus Box 1137, St Louis, MO 63130, USA (JM); School of Zoology, University of Tasmania, GPO Box 252-5, Hobart, Tasmania, Australia 7001 (RS).

Niveoscincus "snow skink" is the largest genus of lizards in Tasmania, but little literature is available on the ecology of the seven species discussed here. They were examined by studying the vegetation associations and natural history of all *Niveoscincus* species except *N. palfreymani.* Most were found to be primarily either ground-dwelling, saxicolous or arboreal, although a few species, such as *N. microlepidotus,* showed a combination of these habits. Saxicolous and heath/rock-dwelling species were restricted to more open habitats. Ground-dwelling species, on the other hand, were widespread and found in many different habitats but not in open rocky areas. Arboreal species were found in a wide range of forest habitats from sea-level to the treeline. The species studied were found to have significantly different, although partially overlapping habitat preferences.
Key Words: alpine, habitat, lizard, *Niveoscincus,* Tasmania.

INTRODUCTION

General

The cool to cold temperate climate of Tasmania supports a relatively impoverished reptilian fauna (Cogger & Heatwole 1984), which is composed of 18 lizard and three snake species. Until recently, the majority of the lizard species were placed in the genus *Leiolopisma* (Wilson & Knowles 1988) but recently (Hutchinson *et al.* 1990) this has been recognised as polyphyletic . Hutchinson *et al.* (1990) revised the genus using morphological and molecular characters; one consequence of this revision was the formation of *Niveoscincus* (= "snow skink"). This is the largest of the ten genera of lizards known from Tasmania, with seven of the eight described species occurring on the island.

Although the taxonomy of *Niveoscincus* has been clarified, little published literature on any ecological aspects of the species' biology is available. The most extensive review of the ecology, biogeography and natural history of Tasmanian lizards was provided by Rawlinson (1974); this remains the only detailed examination recorded. However, this work is now outdated, as it predated the description of *Niveoscincus* and did not include all the species now recognised. We provide the first quantitative investigation of the vegetation associations and natural history of seven species of *Niveoscincus.* The work described here formed part of a larger study of Tasmanian snow skinks (Melville 1998).

Current knowledge of the ecology of *Niveoscincus* species

Since the review by Rawlinson (1974), three new species, *Niveoscincus greeni* and *N. coventryi* (Rawlinson 1975) and *N. orocryptus* (Hutchinson *et al.* 1988), have been described and *N. microlepidotus* has been redescribed (Hutchinson *et al.* 1989). Previously *N. microlepidotus* was included in *N. pretiosus. N. microlepidotus* and *N. orocryptus,* along with *N. greeni,* are the three truly alpine species found in Tasmania. Brief descriptions of the habitat and distributions of these alpine species are available in Hutchinson *et al.* (1988, 1989), Hutchinson & Schwaner (1991) and Hutchinson & Hudson (1998). More detailed studies of the ecology and behaviour of *N. microlepidotus* have been provided by Melville & Swain (1997a, b, 1998) and Olsson & Shine (1998a, b). The three alpine species occur in largely disjunct populations on mountain tops above 1000 m in southern Tasmania (*N. microlepidotus*), western Tasmania (*N. orocryptus*) and northeastern and central Tasmania (*N. greeni*) (Hutchinson & Schwaner 1991, Hutchinson & Hudson 1998). *N. microlepidotus* and *N. greeni* occur above the treeline and are restricted to more open areas, particularly dolerite boulder fields. *N. orocryptus,* on the other hand, is reported to be restricted to the treeline in some areas, such as Mt Eliza, but occurs above this point in other areas, such as Mt Hartz (Hutchinson *et al.* 1988).

The general ecology and distribution of the metallic skink, *N. metallicus,* are better known (Rawlinson 1974). Also, some thermoregulatory data have been incorporated into larger studies (Bennett & John-Alder 1986), and there are a number of recent papers dealing with reproductive physiology (Swain & Jones 1994, 1997, Jones & Swain 1996, Jones *et al.* 1998). This ground-dwelling species has a wide distribution and occurs in many habitats over a broad altitudinal range, from dry sclerophyll woodlands to sub-alpine heaths. The environmental disturbance associated with development appears to have benefited this species, and it is commonly found in suburban gardens and in vegetation along roadsides.

The other ground-dwelling species considered in this paper, *N. coventryi,* has been little studied. *N. coventryi* is a cryptic lizard found in tall highland forests in Victoria, where it occurs in the thick layers of bark and leaf litter (Webb 1985). Although the species has been incorporated into larger studies of thermoregulation and general ecology (Webb 1985, Bennett & John-Alder 1986), no detailed ecological data are available.

The remaining two species which have been investigated in this study are the arboreal snow skink *N. pretiosus* and

the saxicolous species *N. ocellatus*. *N. pretiosus* is a small, agile skink which occurs throughout Tasmania, up to an altitude of 1000 m (treeline). It is found mainly on fallen branches and trunks which form breaks in the forest canopy. However, in western Tasmania it is also saxicolous in some areas (Hutchinson & Schwaner 1991).

N. ocellatus is the largest species of *Niveoscincus* on mainland Tasmania and occurs on rocky outcrops in eastern, central and northern Tasmania. There is a very large range in body size in this species. Individuals from populations at higher altitudes (up to 1000 m) are almost one-third larger than those at sea-level (E. Wapstra, pers. comm.). Little work has been published for this species, although Wapstra & Swain (1996) examined feeding ecology, and reproductive cycles and annual profiles of reproductive steroid hormones have recently been described (Jones *et al.* 1997).

The remaining species of *Niveoscincus* is *N. palfreymani* (the Pedra Branca skink) which is the only endangered Tasmanian reptile listed as threatened. Both the *Tasmania Threatened Species Protection Act* 1995 and the *Commonwealth Endangered Species Protection Act* 1992 record it as "vulnerable". It is also the largest species of *Niveoscincus*, with snout–vent lengths of up to 90 mm. This species consists of a single population living on a rocky islet (Pedra Branca) 26 km off the south coast of Tasmania. In 1997, the population had dropped from around 500 animals to about 200 (N. Brothers, pers comm.). Pedra Branca is a barren windswept island with no vegetation. The lizards feed on fish dropped or regurgitated by the bird colonies. Consequently, the lizard population is dependent on the wellbeing of the bird colony. Although little has been published on this species, a monitoring programme has been maintained on the bird and lizard populations of Pedra Branca since 1978. All lizards are toe-clipped, and life-history data have been collected by the Tasmanian National Parks and Wildlife Service. The only published data on this species are provided by Rounsevell *et al.* (1985).

MATERIALS AND METHODS

Study Species

Niveoscincus is a group of small to medium-sized lygosomine skinks, diagnosed by well-developed prefrontal shields, paired or fused frontoparietals, a distinct interparietal shield and a moveable lower eyelid with a moderate to large transparent palpebral disc (Hutchinson *et al.* 1989). Six species are endemic to Tasmania: *N. greeni, N. microlepidotus, N. ocellatus, N. orocryptus, N. palfreymani* and *N. pretiosus* (fig. 1). The distribution of *N. metallicus* extends from Tasmania into southern Victoria, while *N. coventryi* is restricted to southeastern Australia. Since there is some uncertainty about the taxonomic status of the *N. orocryptus* population at Mt Hartz (Hutchinson & Schwaner 1991, Melville & Swain 1998), the two populations of *N. orocryptus* that we examined were treated separately.

Hutchinson & Schwaner (1991) identified three species groupings in *Niveoscincus*: ground-dwelling (*N. coventryi* and *N. metallicus*), arboreal (*N. pretiosus* and *N. orocryptus* [Mt Eliza population]) and saxicolous species (*N. greeni, N. microlepidotus, N. ocellatus* and *N. orocryptus* Mt Hartz population). The saxicolous species can be further divided into specialists (*N. greeni* and *N. ocellatus*) and heath/rock-dwelling species (*N. microlepidotus* and *N. orocryptus* [Mt Hartz population]) (Melville 1998).

Fieldwork

Habitat associations were recorded at 11 field sites chosen to cover a broad range of habitat types and altitudes (table 1). Most species were studied at two field sites. The data were recorded by starting at a randomly determined location at each field site and moving back and forth across the site to ensure coverage of the entire range of microhabitats available. Measures of canopy heights and undergrowth vegetation

TABLE 1
Location of field sites with a brief vegetation description of the microhabitats occupied by each study species

Species	Site	n	Basking surface	Undergrowth type	Canopy type	Substrate type
N. coventryi	Mt St Leonards	41	ground/litter	tall shrubs/trees (>2 m)	tall eucalypts (>30 m)	soil/deep litter
N. greeni	Ben Lomond	55	boulder	usually absent	absent	dolerite boulders
N. greeni	Mt Pelion East	66	boulder	usually absent	absent	dolerite boulders
N. metallicus	Orford	71	ground/litter/rock	small shrubs (<1 m)	eucalypts (<15 m)	soil/rocks/litter
N. metallicus	Clarence Lagoon	60	ground/litter/rock	small-tall shrubs (0–2 m)	eucalypts (15–40 m)	soil/rocks/litter
N. microlepidotus	Mt Hartz	55	heath/boulder	alpine heath (<0.8 m)	absent	peat/dolerite boulders
N. microlepidotus	Mt Wellington	49	heath/boulder	alpine heath (<0.8 m)	absent	peat/dolerite boulders
N. ocellatus	Central Plateau	61	boulder	sub-alpine heaths (<1 m)	absent	sand/dolerite boulders
N. ocellatus	Orford	37	rock/boulder	low shrubs (<0.8 m)	eucalypts (<15 m)	dolerite rocks/litter
N. orocryptus	Mt Eliza	66	heath/boulder/ground	alpine heath (<1.5 m)	eucalypts (<15 m)	peat/dolerite boulders
N. orocryptus	Mt Hartz	75	heath/boulder	alpine heath (<0.8 m)	absent	peat/dolerite boulders
N. pretiosus	Clarence Lagoon	56	log/rock	small-tall shrubs (0–2 m)	eucalypts (15–40 m)	soil/rocks/litter
N. pretiosus	Pirates Bay	49	log	tall shrubs/trees (>1.5 m)	eucalypts (20–50 m)	soil/litter

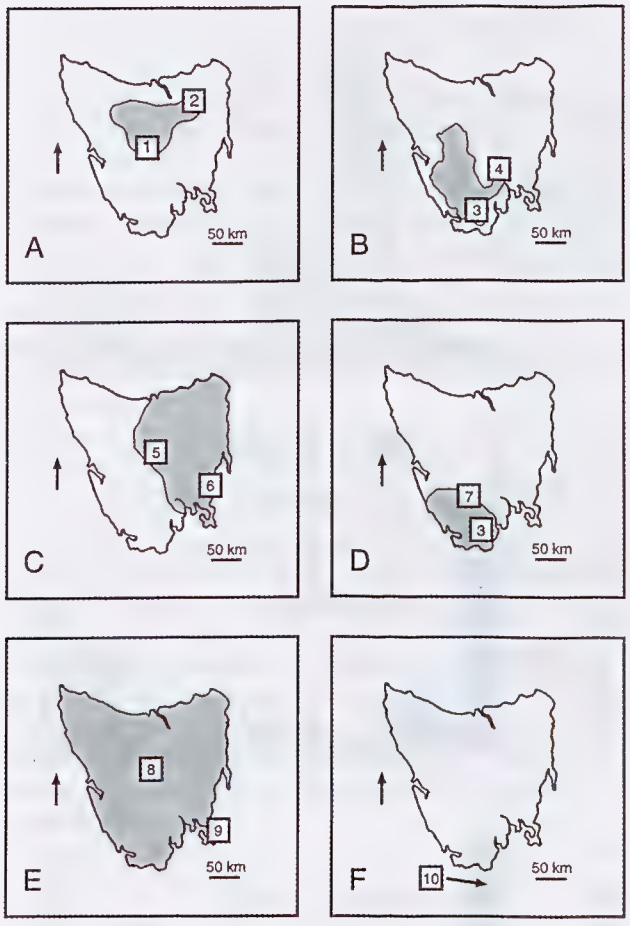


FIG. 1 — Location of field sites and approximate distributions (shaded) on the Tasmanian mainland of the six endemic species of Niveoscincus. *Numbers identify field sites (see table 1); shading indicates distribution.*
A – N. greeni; *B* – N. microlepidotus; *C* – N. ocellatus; *D* – N. orocryptus; *E* – N. pretiosus and *N. metallicus*; *F* – N. palfreymani. Niveoscincus palfreymani *is restricted to a small islet off the south coast of Tasmania (Field Site 10). The distribution of* N. coventryi *is not provided:* N. coventryi *does not occur in Tasmania, while* N. metallicus *extends into southeastern Australia.*
Species (site name) collected at each site: 1 – N. greeni *(Mt Pelion East); 2* – N. greeni *(Ben Lomond); 3* – N. microlepidotus, N. orocryptus *(Mt Hartz); 4* – N. microlepidotus *(Mt Wellington); 5* – N. ocellatus *(Central Plateau); 6* – N. ocellatus, N. metallicus *(Orford); 7* – N. orocryptus *(Mt Eliza); 8* – N. metallicus, N. pretiosus *(Clarence Lagoon); 9* – N. pretiosus *(Pirates Bay); 10* – N. palfreymani *(Pedra Branca).*

cover were based on visual estimates. Prior to fieldwork, measurements of a range of these three factors were conducted to allow more accurate visual estimations to be made. The number of lizards observed for this study varied between field sites, and the total number of specimens for which vegetation association was recorded at each site ranged from 49 to 65. Whether or not a lizard was captured, ten structural characteristics of the vegetation were recorded: (1) canopy type: eucalypt, rainforest or other; (2) visual estimate of percent canopy cover in a 3 m^2 radius surrounding lizard; (3) visual estimate of canopy height in metres; (4) basking surface — rock, litter, ground, log, branch or tree trunk; (5) undergrowth vegetation type — trees (> 2 m), shrubs (1–2 m), shrubs (< 1 m), ground cover, grass or none; (6) distance to the nearest vegetation in centimetres; (7) visual estimate of percentage undergrowth vegetation cover in a 3 m^2 radius surrounding lizard; (8) average measure of undergrowth vegetation height in metres; (9) substrate type — litter, rock, gravel, soil, and combinations of these; and (10) visual estimation of substrate wetness, measured on a scale of 1–6 (1 = dry substrate, 6 = surface water visible).

The data collected from these observations were analysed using ANOVA to identify differences between species and species groups. In no cases were assumptions of normality violated, and analyses were carried out, therefore, without data transformation. Fishers LSD *post hoc* tests were used to identify the comparisons that accounted for any significant differences.

RESULTS

The seven species we studied were associated with a range of different vegetation types (table 2). The ground-dwelling species (*N. coventryi* and *N. metallicus*) were recorded in grasslands, dry sclerophyll, wet sclerophyll and mixed forests. The saxicolous species were observed in more open areas: *N. greeni* exclusively in alpine boulder fields and *N. ocellatus* in dry sclerophyll woodlands and sub-alpine heaths. The heath/rock-dwelling species (*N. microlepidotus* and *N. orocryptus* [Mt Hartz population]) were recorded in all habitat types which occur above the treeline. The arboreal species (*N. pretiosus* and *N. orocryptus* [Mt Eliza population]) were observed in a range of forest habitats from wet sclerophyll to alpine woodlands.

The distance to the nearest undergrowth vegetation varied both interspecifically ($F_{8,755} = 86.18$, $P < 0.001$) and intraspecifically (fig. 2). The two populations of *N. microlepidotus* varied significantly ($F_{1,102} = 20.52$, $P < 0.001$), which may be a result of very different levels of vegetation cover at the two field sites. Mt Hartz has more extensive areas of alpine heathlands than Mt Wellington. *N. greeni* and *N. ocellatus* showed no intraspecific differences in distance to the nearest vegetation, yet there were significant differences between these species ($P < 0.001$). Overall, the ground-dwelling species were found significantly closer to vegetation than saxicolous ($P < 0.001$), heath/rock-dwelling ($P = 0.034$) and arboreal species ($P < 0.001$).

TABLE 2
Range of vegetation types recorded for each species at each field site

Species	Field sites	Habitat description*
N. coventryi	Mt St Leonards	Wet sclerophyll forest
N. greeni	Ben Lomond	Alpine boulder field
	Mt Pelion East	Alpine boulder field
N. metallicus	Clarence Lagoon	Wet/dry sclerophyll forest
	Orford	Dry sclerophyll woodland
N. microlepidotus	Mt Hartz	Alpine boulder field & alpine heathland
	Mt Wellington	Alpine boulder field & alpine heathland
N. ocellatus	Central Plateau	Boulder fields in wet heathlands
	Orford	Rocky slopes in sclerophyll woodlands
N. orocryptus	Mt Eliza	Sub-alpine sclerophyll woodland
	Mt Hartz	Alpine boulder field & alpine heathland
N. pretiosus	Clarence Lagoon	Wet sclerophyll forest & mixed forest
	Pirates Bay	Wet sclerophyll forest

* Sclerophyll forest — open canopy which is over 15 m in height and dominated by *Eucalyptus* spp. Dry sclerophyll has a low sparse understorey, usually under 1.2 m in height. Wet sclerophyll has a tall dense understorey, at times up to 5 m in height.

Boulder field — large dolorite boulders ranging in size from 0.2 m up to several metres in diameter. Little or no vegetation is present.

Sclerophyll woodland — sparse or patchy canopy under 15 m in height and dominated by *Eucalyptus* spp. Understorey usually sparse and below 1.2 m in height.

Heathland — canopy absent, vegetation dense and low.

Mixed forest — tall dense canopy dominated by *Eucalyptus* spp. with a subcanopy and tall understorey dominated by temperate rainforest species, such as *Nothofagus cunninghamii*.

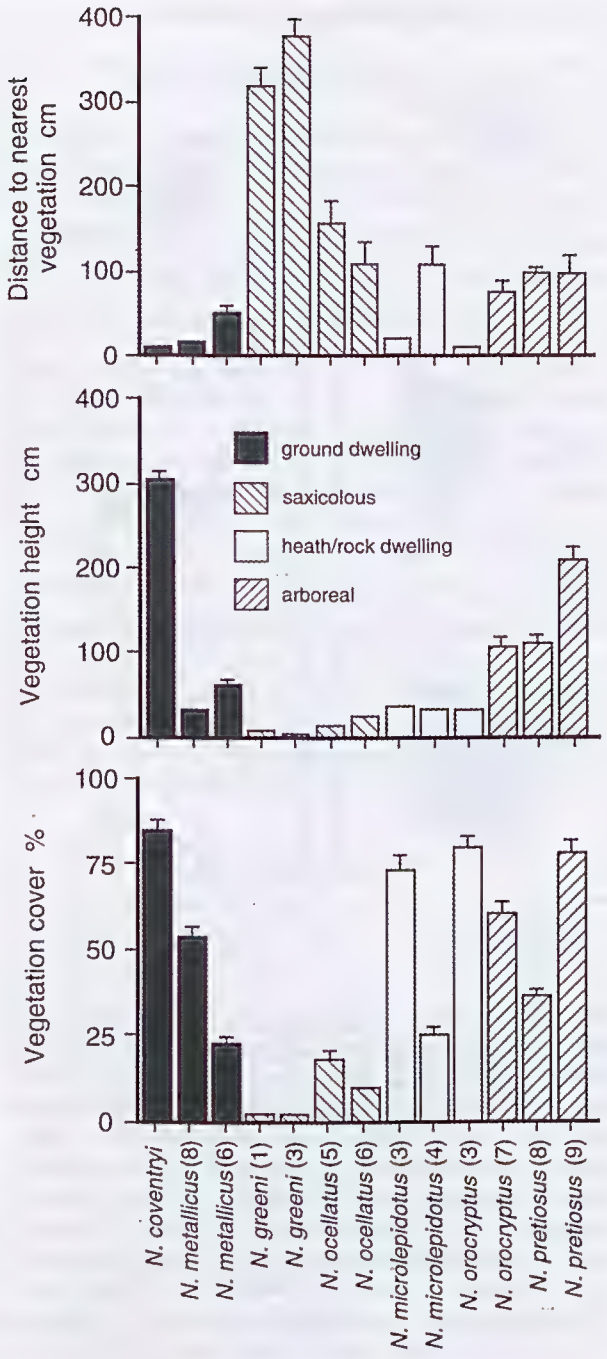


FIG. 2 — Habitat vegetation characteristics associated with each species. Values are means ± 1 standard error. Numbers in parentheses are site locations identified in figure 1.

The heath/rock-dwelling and saxicolous species were observed in areas with significantly lower undergrowth height than the arboreal and ground-dwelling species ($F_{3,760} = 104.36$, $P < 0.001$) (fig. 2). This result may have been influenced by the fact that the majority of the heath/rock-dwelling and saxicolous species occupy alpine habitats, and these tend to have lower vegetation structure. However, the height of the vegetation surrounding *N. ocellatus* did not differ significantly from other saxicolous ($P = 0.089$) and heath/rock-dwelling species ($P = 0.055$), even though this is a species with many lowland populations. *N. ocellatus* and *N. metallicus* did differ significantly in the height of the surrounding undergrowth vegetation at the Orford field site ($P < 0.001$). The vegetation height associated with ground-dwelling lizards was highly variable and reflected the wide range of vegetation types occupied by these species; this encompassed the spectrum from grasslands to tall wet sclerophyll forest (table 2).

The percentage of undergrowth vegetation cover was variable between sites and species (fig. 2). There was no significant difference between vegetation cover recorded for the ground-dwelling, arboreal and heath/rock dwelling species. However, the saxicolous species were recorded in areas with significantly less vegetation cover than the other species ($P < 0.001$). There were also significant differences between species at the same field sites. *N. ocellatus* was recorded from locations with significantly less vegetation cover than *N. metallicus* at the Orford site ($P < 0.001$). *N. metallicus* also differed significantly from *N. pretiosus* at

Clarence Lagoon ($P < 0.001$); it used the ground and rocks, while *N. pretiosus* used the large number of fallen tree trunks and branches available.

Perch height (height above ground when sighted) was significantly higher in both saxicolous and arboreal species than in the other species groups ($P < 0.001$ in all *post hoc* comparisons) (fig. 3), while the heath/rock-dwelling species differed significantly from the ground-dwelling species ($P = 0.021$). The perch height of *N. ocellatus* and *N. metallicus* varied significantly at the Orford site ($P < 0.001$) and *N. metallicus* and *N. pretiosus* differed significantly in perch height at Clarence Lagoon ($P < 0.001$). There was no signifcant difference in the perch height of saxicolous and arboreal species.

There were highly significant differences in canopy height ($F_{3,760} = 305.41$, $P < 0.001$) and cover ($F_{3,760} = 287.21$, $P < 0.001$) recorded for the groups of species (fig. 3). This was mainly due to the lack of canopy in any of the field sites where the saxicolous and heath/rock dwelling species occur, except for *N. ocellatus* at Orford. The alpine species were not observed when a canopy was present, with the exception of *N. orocryptus* at Mt Eliza. *N. ocellatus* occupied areas at the Orford site which had significantly less canopy cover ($P < 0.001$) and a lower canopy height ($P < 0.001$) than those used by *N. metallicus*. *N. coventryi* was observed to occupy locations with significantly more canopy cover and a taller canopy than all other species ($P < 0.001$ for all comparisons).

DISCUSSION

Habitat Associations

Niveoscincus coventryi

This species has previously been studied in the central highlands of Victoria and described as a cryptic species associated with deep layers of litter and vegetation (Rawlinson 1975, Greer 1982, Brown & Nelson 1993). Webb (1985), in a study of microhabitat use in some southeastern Australian skinks, found that *N. coventryi* spent 92% of their time in the litter. This is very similar to the findings of this study, where the lizards occupied the deep litter layers on the ground. *N. coventryi* occupied the most closed microhabitat of all *Niveoscincus* species. It is very cryptic, basking in small patches of dappled sunlight.

Niveoscincus greeni

This is the first study to quantify the microhabitat of *N. greeni*, which has previously been described as a saxicolous species (Rawlinson 1975, Greer 1982, Hutchinson & Schwaner 1991), occupying a similar type of microhabitat to *N. microlepidotus*. Our data support the conclusion that *N. greeni* is saxicolous, as it was found only in open boulder fields, even when other microhabitats were only metres away. It is much more specialised in its microhabitat occupation than *N. microlepidotus*. Over the three years of our study, *N. greeni* was never seen outside the open boulder fields. At the Mt Pelion East field site, *N. greeni* and *N. microlepidotus* occur in syntopy but occupy very different microhabitats. *N. greeni* occupies small patches of boulders, while *N. microlepidotus* is found only in heath and peat areas. Hutchinson & Hudson (1998) suggest that these two species may occur sympatrically through most of the Central Plateau peaks, with a consistent separation in habitat usage.

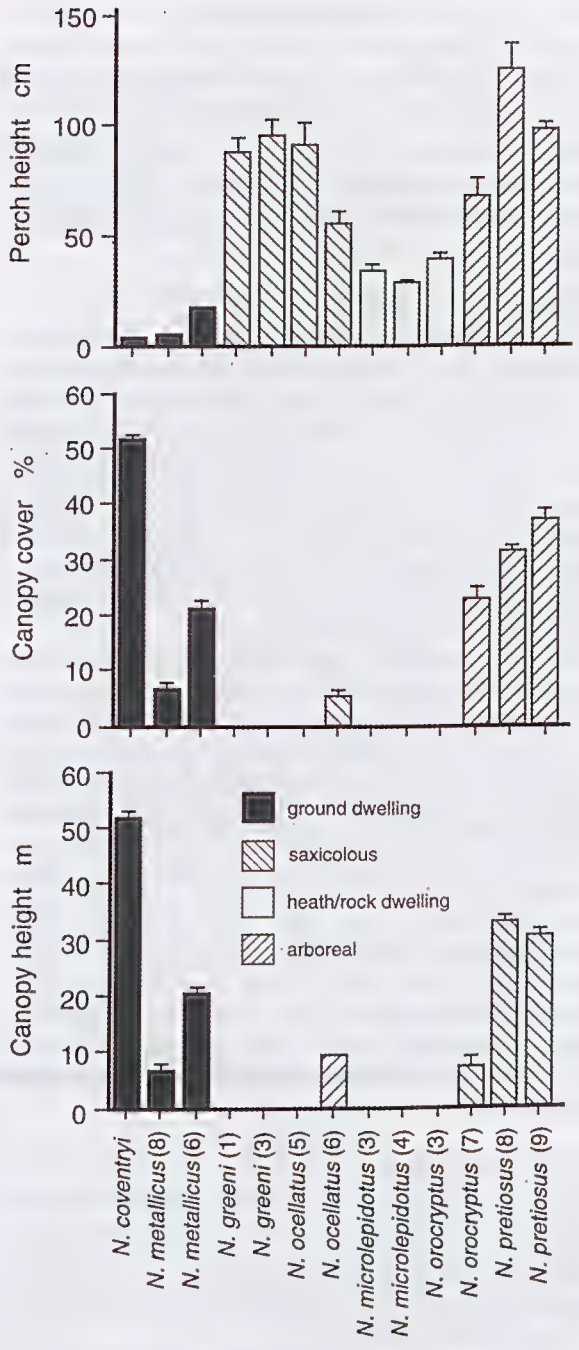


FIG. 3 — Perch height and canopy characteristics associated with each species. Values are means ± 1 standard error. Numbers in parentheses are site locations identified in figure 1.

Niveoscincus metallicus

All previous reports have described *N. metallicus* as a ground-dwelling and relatively cryptic species, found in a wide range of habitats (Rawlinson 1974, Hutchinson & Schwaner 1991, Melville & Swain 1997a, b). Our analysis supports this description; this species occupies shaded microhabitats with medium to dense vegetation cover, soil and thick litter.

N. metallicus appears to be restricted to a more closed microhabitat at the higher altitude Clarence Lagoon site (900 m a.s.l.) than at Orford (50 m a.s.l.). There was a dense canopy with more undergrowth, and the lizards at this site tended to bask on rocks to a greater extent than the

lizards at Orford, despite the fact that there were greater numbers of logs available for basking at Clarence Lagoon. At the Orford field site, *N. metallicus* occupies an open microhabitat but is more closely associated with litter layers and ground-cover vegetation. These observations are consistent with the conclusions of Melville & Swain (1997a), who found that N. metallicus occupied a fairly closed microhabitat at a high-altitude site on Mt Wellington (1000 m a.s.l.) in southern Tasmania.

Niveoscincus microlepidotus

The results obtained from our analysis of microhabitat occupation by *N. microlepidotus* support the existing descriptions of habitat preferences for this species. Hutchinson *et al.* (1989) described *N. microlepidotus* as an alpine species that occurs in large numbers in dolerite boulder fields above 1000 m in southern Tasmania. Our study confirms that *N. microlepidotus* has a preference for the open boulder fields, on which it basks, in agreement with our earlier study of this species on Mt Wellington (Melville & Swain 1997a). However, we find that *N. microlepidotus* also uses other microhabitats: alpine heaths and sub-alpine woodlands.

We have identified a large difference in microhabitat occupation at Mt Wellington and Mt Hartz. At Mt Hartz, *N. microlepidotus* occupied the heathland, basking on branches, the top of heath plants, the ground or cushion plants, as well as the few available rocks. These observations suggest that *N. microlepidotus* is an effective alpine generalist. Open boulder fields may represent the preferred microhabitat, since the lizards are most abundant in this habitat (Melville & Swain 1997a); nevertheless, unlike *N. greeni*, they are also able to exploit suboptimal microhabitats such as the heathlands. Where *N. microlepidotus* and *N. greeni* co-occur, the latter species is the sole occupant of the boulder habitat, suggesting that competitive exclusion may exist, although separation may also result from differences in environmental tolerances or thermoregulatory requirements.

Niveoscincus ocellatus

Our study confirms that *N. ocellatus* is a saxicolous species, occurring in open, rocky outcrops. It is the only species of *Niveoscincus* that both is wholly saxicolous and occurs at low altitudes. There was no significant difference in microhabitat occupation between the two field sites, despite very large differences in macrohabitat.

The Orford field site is lowland woodland with shrubby undergrowth, extensive areas of litter, bare ground and outcrops of rock. Thus, there are many different microhabitats that *N. ocellatus* could occupy. Despite this, the lizards use only a restricted microhabitat similar to that recorded from the open wet heathlands of the Central Plateau.

Niveoscincus orocryptus

Mt Eliza is the type locality for *N. orocryptus*, which was only recognised in 1988 by Hutchinson *et al.* (1988), who described it as a semi-arboreal species, which spends much of its time moving through the shrubs and rocky outcrops in sub-alpine areas. They also observed it climbing small, stunted eucalypt trees. This description agrees closely with our observations of this species at this site. Lizards were observed to bask on both shrubs and rocks and were often seen basking at heights above 1 m. We never found *N. orocryptus* above the treeline and it appears to be restricted to the sub-alpine woodland, which occurs in a small band at about 1000 m at Mt Eliza.

However, *N. orocryptus* at the Mt Hartz field site occupy a significantly different microhabitat. Moreover, at Mt Hartz this microhabitat was indistinguishable from that used by *N. microlepidotus* at that site. The extensive overlap in microhabitat use by these two species is further confused by their similarity in appearance; identification had to be confirmed by capture. Hutchinson & Schwaner (1991) reported that, in the far southwest of Tasmania, *N. microlepidotus* and *N. orocryptus* are morphologically indistinguishable, and there are not even strong genetic differences between them. Consequently, possible hybridisation between *N. orocryptus* and *N. microlepidotus* at Mt Hartz may play an important role in the significant difference in microhabitat occupation between the two populations of *N. orocryptus*.

Niveoscincus pretiosus

This is a species which occupies forested areas, especially thickly vegetated habitats. *N. pretiosus* was observed to move around on large fallen trees which create breaks in the canopy, providing large patches of sunlight for basking.

The two field sites used in this study are very different, yet the lizards occupy very similar microhabitats. The Pirates Bay field site is a highly disturbed wet sclerophyll forest. The land has been cleared and the current vegetation is regrowth. Lizards were recorded in greatest numbers moving around on large trees that had been bulldozed into piles in the forest. There were very few rocks available, and the lizards used logs exclusively as basking sites. The Clarence Lagoon field site, on the other hand, has large outcrops of rocks but *N. pretiosus* were rarely recorded using them as basking sites. The lizards at Clarence Lagoon consistently occupy the extensive areas of fallen trees.

N. pretiosus has been described previously as a scansorial species adapted to living on fallen logs, trees or rock outcrops (Hutchinson *et al.* 1989). We found that it occurs in a range of habitats where there are trees or where rocks outcrop, using the elevated surfaces of fallen logs, the trunks and lower branches of trees and, less frequently, rocks for basking sites. On some of the small offshore islands inhabited by *N. pretiosus*, trees are almost or totally absent, and in these areas it is saxicolous (Hutchinson *et al.* 1989). The current study indicates that, in central and southeastern mainland Tasmania, *N. pretiosus* is a forest-dwelling, arboreal species.

CONCLUSIONS

In terms of general biology *Niveoscincus* forms a fairly homogenous genus of closely related species. All species have diurnal activity patterns, and are active foragers (having a predominantly arthropod-based diet), shuttling heliotherms. All of the species thermoregulate behaviourally by restricting activity times, altering body postures and shuttling between sun and shade. They have different, although partially overlapping geographic distributions and habitat preferences. Despite these similarities, *Niveoscincus* has radiated significantly in ecology and behaviour. Most of the species are either primarily terrestrial, saxicolous or arboreal. A few species, such as *N. microlepidotus*, show a combination of saxicolous, ground-dwelling and arboreal behaviours.

The ecological range of each species is summarised in

figure 4. The saxicolous and heath/rock-dwelling species are restricted to more open habitats above the treeline, with the exception of *N. ocellatus*, which occurs in open rocky situations in lowland areas of Tasmania. The ground-dwelling species, on the other hand, are widespread and found in many different habitats. However, they do not occur in open rocky areas or above the treeline. The arboreal species are found in a wide range of forest habitats from sea-level to the treeline. Recently completed molecular work (Melville, pers. obs.) indicates that there are a number of adaptive clades within *Niveoscincus*. The ground-dwelling species are ancestral, with subsequent evolution of the arboreal species; the most recently derived species are the heath/rock-dwelling and saxicolous species respectively. Thus, *Niveoscincus* appears to represent an adaptive radiation of ecological and behavioural characteristics.

ACKNOWLEDGEMENTS

We thank the Hobart City Council for allowing work in the Mount Wellington Reserve and the Department of Environment and Land Management for permission to study in various Tasmanian National Parks. We are also grateful to the Victorian Department of Conservation and Natural Resources for permission to collect and observe *N. coventryi*. We appreciate comments made by R. Glor on early drafts of this paper.

REFERENCES

BENNETT, A.F. & JOHN-ALDER, H., 1986: Thermal relations of some Australian skinks (Sauria: Scincidae). *Copeia* 1986: 57–64.

BROWN, G.W. & NELSON, J.L., 1993: Influence of successional stage of *Eucalyptus regnans* (mountain ash) on habitat use by reptiles in the Central Highlands, Victoria. *Aust. J. Ecol.* 18: 405–417.

COGGER, H. & HEATWOLE, H., 1984: The Australian Reptiles: origins, biogeography, distribution patterns and island evolution. *In* Archer, M. & Clayton, G. (Eds): *VERTEBRATE ZOOGEOGRAPHY AND EVOLUTION IN AUSTRALASIA.* Hesperian Press, Carlisle, Western Australia: 343–360.

GREER, A.E., 1982: A new species of *Leiolopisma* (Lacertilia: Scincidae) from Western Australia, with notes on the biology and relationships of other Australian species. *Rec. Aust. Mus.* 34: 549–573.

HUTCHINSON, M.N. & HUDSON, S., 1998:. Reptiles. *In* Driessen, M.M., Comfort, M.D., Jackson, J., JBalmer, J., Richardson, A.M.M. & McQuillan, P.B. (Eds): *WILDERNESS ECOSYSTEM BASELINE STUDIES (WEBS): PELION PLAINS–MT OSSA. Tasm. Parks and Wildl. Serv. Wildl. Rep.* 98/2: 183–186.

HUTCHINSON, M.N. & SCHWANER, T.D., 1991: Genetic relationships among the Tasmanian scincid lizards of the genus *Niveoscincus*. *J. Herpetol.* 25: 49–58.

HUTCHINSON, M.N., SCHWANER, T.D. & MEDLOCK, K., 1988: A new species of scincid lizard (Lygosominae: *Leiolopisma*) from the highlands of Tasmania. *Proc. R. Soc. Vict.* 100: 67–73.

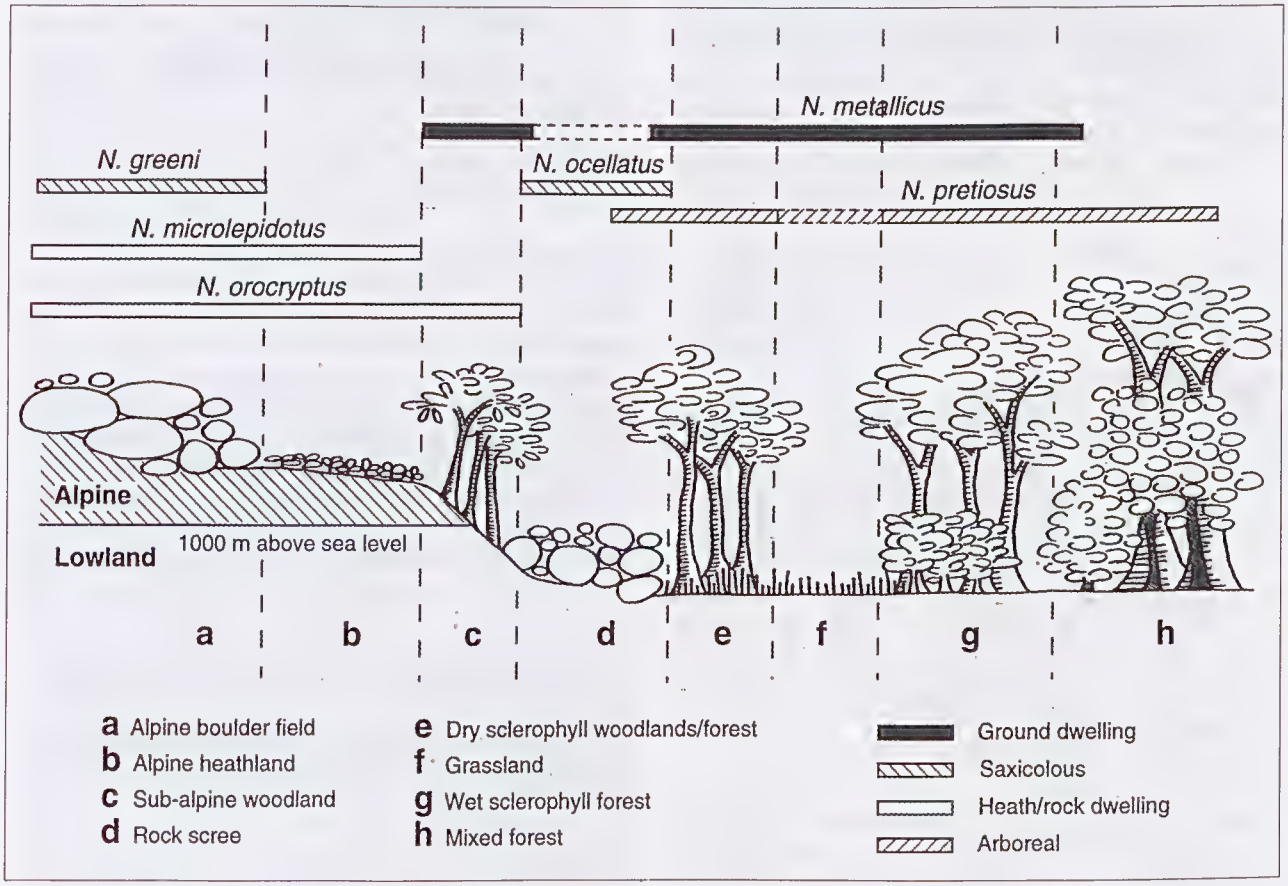


FIG. 4 — Summary of habitat associations for all Tasmanian species studied.

HUTCHINSON, M.N., ROBERTSON, P. & RAWLINSON, P.A., 1989: Redescription and ecology of the endemic Tasmanian scincid lizards *Leiolopisma microlepidotum* and *L. pretiosum*. *Pap. Proc. R. Soc. Tasm.*123: 257–273.

HUTCHINSON, M.N., DONNELLAN, S.C., BAVERSTOCK, P.R., KREIG, M., SIMMS, S. & BURGIN, S., 1990: Immunological relationships and generic revision of the Australian lizards assigned to the genus *Leiolopisma* (Scincidae: Lygosominae). *Aust. J. Zool.* 38: 535–554.

JONES, S. & SWAIN, R., 1996:. Annual reproductive cycle and annual cycles of reproductive hormones in plasma of female *Niveoscincus metallicus* (Scincidae) from Tasmania. *J. Herpetol.* 30: 140–146.

JONES, S., WAPSTRA, E. & SWAIN, R., 1997: Asynchronous male and female gonadal cycles and plasma steroid concentrations in a viviparous lizard, *Niveoscincus ocellatus* (Scincidae), from Tasmania. *Gen. Comp. Endocrinol.* 108: 271–281.

JONES, S.M, BENNETT, E.J. & SWADLING, K.M., 1998: Lipids in yolks and neonates of the viviparous lizard *Niveoscincus metallicus*. *Comp. Biochem. Physiol.* 121B: 465–470.

MELVILLE, J., 1998: The evolution of locomotory mode in the lizard genus *Niveoscincus*. Unpubl. PhD thesis, School Zool., Univ. Tasm.: 186 pp.

MELVILLE, J. & SWAIN, R., 1997a: Spatial separation in two sympatric skinks, *Niveoscincus microlepidotus* and *N. metallicus*, from Tasmania. *Herpetologica* 53: 126–132.

MELVILLE, J. & SWAIN, R., 1997b: Daily and seasonal activity patterns in two species of high altitude skinks, *Niveoscincus microlepidotus* and *N. metallicus*, from Tasmania. *J. Herpetol.* 31: 29–37.

MELVILLE, J. & SWAIN, R., 1998: Evolutionary relationships within the snow skinks (Squamata: Scincidae: *Niveoscincus*) of Tasmania. *Aust. Biol.* 11: 22–25.

OLSSON, M. & SHINE, R., 1998a: Chemosensory mate recognition may facilitate prolonged mate guarding by male snow skinks, *Niveoscincus microlepidotus*. *Behav. Ecol. Sociobiol.* 43: 359–363.

OLSSON, M. & SHINE, R., 1998b: Timing of parturition as a maternal care tactic in an alpine lizard. *Evolution* 52: 1861–1864.

RAWLINSON, P.A., 1974: Biogeography and ecology of the reptiles of Tasmania and the Bass Strait area. *In* Williams, W. D. (Ed): *BIOGEOGRAPHY AND ECOLOGY IN TASMANIA*. W. Junk, The Hague: 291–338.

RAWLINSON, P.A., 1975: Two new lizard species from the genus *Leiolopisma* (Scincidae: Lygosominae) in southeastern Australia and Tasmania. *Mem. Natl Mus. Vict.* 36: 1–16.

ROUNSEVELL, D., BROTHERS, N. & HOLDSWORTH, M., 1985: The status and ecology of the Pedra Branca Skink Pseudemoia palfreymani. *In* Griggs G., Shine, R. & Ehmann H. (Eds): *BIOLOGY OF AUSTRALIAN FROGS AND REPTILES*. Surrey Beatty & Sons Pty Ltd, Chipping Norton, and R. Soc. NSW: 477–480.

SHINE, R., 1980: "Costs" of reproduction in reptiles. *Oecologia* 46: 92–100.

SWAIN, R. & JONES, S., 1994: Annual cycle of plasma testosterone and other reproductive parameters in the Tasmanian skink, *Niveoscincus metallicus*. *Herpetologica* 50: 502–509.

SWAIN, R. AND JONES, S., 1997: Maternal-fetal transfer of 3H-labelled leucine in the viviparous lizard *Niveoscincus metallicus* (Scincidae: Lygosominae). *J. Exp. Zool.* 277: 139–145.

WAPSTRA, E. & SWAIN, R., 1996: The feeding ecology of the Tasmanian spotted skink *Niveoscincus ocellatus*. *Aust. J. Zool.* 44: 205–213.

WEBB, G.A., 1985: Habitat use and activity patterns in some southeastern Australian skinks. *In* Griggs G., Shine, R. & Ehmann H. (Eds): *BIOLOGY OF AUSTRALIAN FROGS AND REPTILES*. Surrey Beatty & Sons Pty Ltd, Chipping Norton, and R. Soc. NSW: 23–30.

WILSON, S.K. & KNOWLES, D.G., 1988: *AUSTRALIA'S REPTILES*. Collins, Sydney.

(accepted 6 September 1999)

THE NATURE OF JOINTING, TASMAN PENINSULA, SOUTHERN TASMANIA

by David Leaman

(with one table, four text-figures and ten plates)

LEAMAN, D.E., 1999 (31:x): The nature of jointing, Tasman Peninsula, southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 133(1): 65–76. ISSN 0080–4703. Leaman Geophysics, GPO Box 320C, Hobart, Tasmania, Australia 7001.

Existing literature describing the joints in high dolerite cliffs and at the Tessellated Pavement on the Tasman Peninsula offers conflicting views concerning their origin. Recent writers have preferred a tectonic origin. Although regional structures do affect both pavement and cliff rocks, these are not pervasive at outcrop scale. The rock pillars of the high cliffs are true, thermally produced columns, and their nature can be demonstrated by direct inspection of polygons. Polygon faces are not readily identified in collections of joint measurements, but some common orientations have been united in cliff exposure to yield ragged lineaments. This yields the illusion of more recent tectonic control, although many such orientations are clearly at least Jurassic in age. The apparently regular patterns of the pavements are regionally variable, and joint continuity and orientation are complex functions of lithology, bed thickness and pre-stressing, with new joints forming due to relaxation and weathering processes. Pavement joints are generally very recent although they too replicate much older structural trends controlled by east–west shears. Pavement ornamentation provides fine examples of physical and chemical weathering processes.
Keywords: Tasmania, dolerite, columnar jointing, Tasman Peninsula, Tessellated Pavement, coastal weathering, jointing.

INTRODUCTION

Recent historical reviews of observations made by French and English explorers before 1803 and by some visitors, such as Charles Darwin in 1836 (e.g. Banks *et al.* 1989, Banks 1998, Banks & Leaman 1999), drew attention to the manner in which important geological features on the Tasman Peninsula in southern Tasmania (fig. 1) have been described and interpreted. Two such features, much mentioned in early (pre 1850) references, are the Tessellated Pavement at Eaglehawk Neck in Permian siltstone and the great cliffs of Jurassic dolerite which extend around the southern coastline of the peninsula.

The joint patterns in each feature have been considered tectonic in origin, and the features have been linked in style and origin (e.g. Carey 1958, 1976).

Various propositions have been published as explanations for the tessellations and the associated joints, but none are supported by regional observations (Banks *et al.* 1989). This paper presents new information about the joints in the Pirates Bay area and suggests an alternative explanation.

Most other observers (including Forsyth 1984, Hergt *et al.* 1989, and the author) presumed that the joints in the dolerite cliffs defined cooling columns. This paper presents the first detailed inspection of the cliffs carried out in order to test the different concepts. Any conclusion is of general significance in evaluation of escarpments and mountain faces in central and eastern Tasmania.

CLIFFS OF CAPES PILLAR AND RAOUL

Early explorers sighting the enormous cliffs of Jurassic dolerite in southeastern Tasmania interpreted them as volcanic or basaltic (e.g. Flinders – Cape Basaltes=Cape Raoul [e.g. pl. 6]; Péron with Baudin – volcanoes rising out of the sea; Darwin – basaltic platforms). Banks *et al.* (1989) and Banks (1998) provided a number of historical references. Every observer, whether French or English, noted the similarities in style and form to occurrences in the basaltic provinces in Europe and regarded the subvertical pillars of rock as columns — and consequently presumed a thermal, cooling origin for the features. It must be stressed that the gross identification depended on the observation of "columns" and the belief that these were due to cooling. Only the scale was abnormal.

After considerable debate during the 19th century, the dolerites were finally understood to be intrusive and post-Triassic in age. The scale of the intrusions remained a surprising element, but the generation of columns during the cooling of large, sill-like intrusions was expected, based on analogies with thick basaltic flows, lava domes and vents (e.g. Hills 1963, Holmes 1965, Kelley 1987). Hills (1963: 362) actually cited the Tasmanian dolerites as exemplars of columnar jointing. This also seems to have been the prevailing view before Carey (1958).

FIG. 1 — Locality map, Tasman Peninsula, southern Tasmania

Carey, after examination of joint patterns as seen in aerial photographs (especially of the Central Plateau of Tasmania), claimed (1958: 230) that in most exposures the "columns" are not usually hexagonal (as would be predicted theoretically if of thermal or shrinkage origin) but are controlled by two, nearly perpendicular dominant directions. Such joints were inferred to be epeirogenic and universal, not cooling joints. No evidence exists that Carey actually examined exposed plateau rocks, and few escarpments provide sufficient appropriate exposure to show detailed or columnar character in plan. The great cliffs are exceptions, as shown below. There is no doubt that, at regional scales, there are usually two nearly normal, penetrative joint systems, and that these could form the illusion of cooling columns.

Hale (1958) offered an alternate view. He considered that joints of thermal origin occurred at all scales and were commonly hexagonal and universal but were overprinted by an extensive conjugate (orthogonal) joint set. He noted that the latter was usually obvious, but that many thermal joints were unrecognised in surface exposures. Hale's study was largely based on underground observations. This view was supported by the detailed work of Hill (1964) at Mersey Bluff.

This conflict in the literature has remained unsettled, but Banks *et al.* (1989), in describing the origin of the cliffs and contained structures, stated

> The columnar cliffs of dolerite owe their form to more or less planar fractures which may individually extend through tens or even hundreds of metres vertically to well over a kilometre horizontally and are spaced from less than a metre to well over two metres apart. Cooling joints some metres apart may be present in the centre of a dolerite body but only close to the contacts are cooling fractures obvious and there they are closely (0.01 to 0.2 m) spaced perpendicular to the contact with much more widely spaced joints parallel to the contact.

Their view: the cliffs do not present true (thermal) columns.

Banks (1998) discussed the origin of the "columns" of the Organ Pipes on Mt Wellington and noted that these appear to be rectangular and not polygonal in section. The discussion noted that the origin of the columns has not been satisfactorily explained and referred to Carey (1958).

Hale (1958) and Leaman (1972, 1978) described the finer, tabular and clearly thermal joints related to contacts, but both authors (and Leaman 1997a) inset this character within a larger scale thermal and columnar context. Such thermal joints define prisms which have long axes normal to boundaries and a frequency governed by distance from contacts. All characteristics may be recognised in areas where other sources of tabular jointing (such as faults) are absent. All authors agreed with Carey (1958) that a platy joint system (closely spaced, generally orthogonal joints defining tabular slabs) may extend across the contact, depending on the sedimentary lithology and degree of metamorphism. Leaman (1997a), however, drew attention to columns up to 5 m across which extend to within a few metres of the top (Single Hill — pls 1, 2) or base of intrusion (Nelson – Ridgeway Road); in these, the polygonal column faces can be distinguished from penetrative semi-regional fractures and a complex of finer, internal and largely thermal joints. In each exemplary location, the nominal hexagons are apparent, the hexagon faces often display marked curvature and, where seen in massive rock, are often marked by a calcite or zeolite filling.

In many situations, for example above the Organ Pipes on Mt Wellington west of Hobart, it is difficult to assess the planar cross section of the rock pillars/columns. They may properly be called columnar cooling joints only if it can be shown that they are indeed thermal in origin. Fractures, fracture zones or parts of the rock mass may be infilled or covered with soil, debris or vegetation, and irregular outcrop relief may compound the problems of block, column or joint definition. Unless the actual "column" tops have been planed and eroded to remove soils and debris, the joint relationships cannot be discerned easily. This explains the uncertainty stated by Banks (1998).

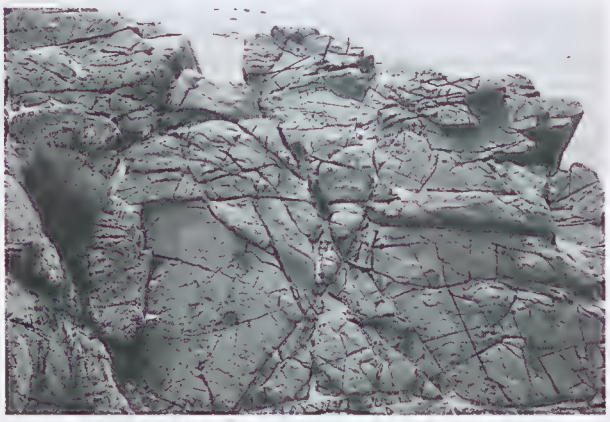


PLATE 1

Detail of column tops at Single Hill. Note the irregular overlapped pattern of the polygons and absence of regional trends and fractures. Most polygons are five- to seven-sided. Comparable character may be observed on clifftops at Cape Raoul and Munro Bight, where columns are much larger. At such sites, all faces can be inspected, but in normal situations much of the detail is obscured by joint fillings, debris or soil cover. Patchy weathering profiles may also conceal this information. This section occurs within 3 m of the intrusion roof.

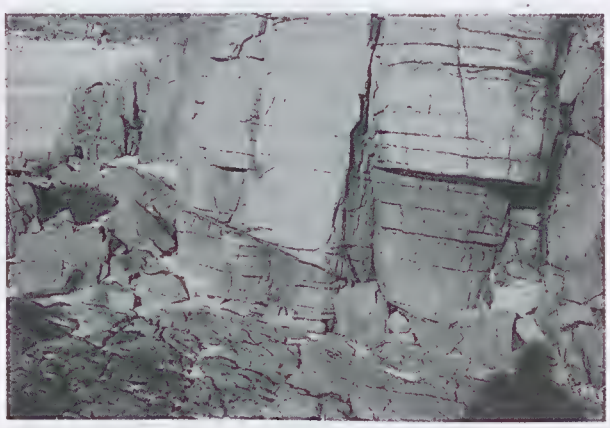


PLATE 2

View of columns shown in plate 1, Single Hill. Note the apparent square section, not confirmed in cross-section, and the frequency of tabular joints normal to the column axis. More recent low angle joints, considered to be true relaxation joints, which disrupt all others are also evident.

Fortunately, most of the clifftops in southern Tasmania were planed and eroded prior to, or during, the last glacial epoch and then covered with a thin veneer of windblown quartz sand. This sand is clearly quite recent (Banks *et al.* 1989) and can be inspected at many sites (e.g. Perdition Ponds–Cape Pillar; Cape Raoul; above Salters Point; north Mount Brown — fig. 1). Dolerite weathering profiles are generally absent around the Tasman Peninsula, and the sand cover, which directly overlies fresh, massive rock, has been patchily and randomly removed in many places. The characteristics of jointing, prior erosion and sand cover may be observed at many outcrops on the Tasman Peninsula between sea level and 400 m. A similar condition applies around the major escarpments of the Great Western Tiers in northern Tasmania, where different glacial period histories have produced similar results (but without the sand cover).

Cliff escarpments near Dolomieu Point, Cape Hauy, Mt Fortescue, Cape Pillar, Mt Brown, Arthurs Peak, Cape Raoul and Salters Point (fig. 1) and others near Pelverata (Snug Tier), Devils Throne (Wellington Plateau) and Mt Parmeener, Fisher Bluff and Devils Gullet (Great Western Tiers), Mt Jerusalem and Pillans Lake (Central Plateau) and Mt Olympus in northwestern Tasmania have been examined in order to establish generality and appraise Carey's 1958 comments. Many localities permit review of exposures at various levels within the intrusions and around nearby shore platforms. Hill (1964) already inferred that columns exist within a large intrusion and that a thermal entablature may be present, unrecognised, in many cases.

Faces in dolerite, whether natural or man-made, display an apparent tangle of joints and fractures. In the less common situation, namely that of the great escarpments, we often see a columnar regularity. In order to define the critical criteria able to separate the orthogonal or polygonal origin of the features it is necessary to consider some exemplary cases where all aspects can be evaluated, and then apply the findings to the more general and more inaccessible situations of the escarpments.

Columnar jointing of thermal origin was described at Single Hill and Ridgeway (Leaman 1997a). Consider what is actually present in these cases.

At Ridgeway, the columns are essentially four-sided, very large and basal to the intrusion. They also plunge shallowly northward and when broken present very hackly surfaces due to other, plentiful joints. One pervasive joint set, essentially the orientation of one column side, is oriented at 305–310°; not obviously related to local structures (intrusive margin or faults), it can be separated from thermal joints of essentially the same orientation, which curve and facet smoothly to produce small accessory faces. The other sides of the columns display most distinctive curved forms, and no other joint replicates this character. Each column retains its form and coherence, and most joints are trapped within its confines. It is possible to observe this at Ridgeway, due to a fortunate conjunction of joint dip and exposure face, but all other slopes in the region are smoothly eroded without scarps. Near the base of the columns and normal to them is another set of closely spaced joints, which mirror the dip and orientation of the intrusive margin. The Ridgeway case is complicated by the 30–40° plunge of the columns, and no cross-sectional shapes can be examined. The diagnostic characters are considered to be the presence of confined joint packages and the curvature and facetting of large and small faces. Morphology is critical.

Single Hill provides a clear, diagnostic example of all factors — including the properties of contacts and associated sedimentary rocks — and the nature of the columns is evident in plates 1 and 2. These do appear to be four-sided or rectangular at first inspection.

Examination reveals the following:

The columns are polygons with up to seven faces, of which four or five are predominant. They can be seen in cross-section and shown to almost wholly enclose a joint package; few joints (at 65 and 330°) cross polygon boundaries. Many joints with these orientations are incipient within the columns. There are many platy joints normal to the column axis (pl. 2) and these are also column-confined.

Figure 2 presents a summary of joint observations in different parts of this intrusion, showing that simple measurement of joints cannot resolve the issue at hand.

Near the roof of the intrusion, where the joints are very platy, different exposures yield distinctive patterns dominated by the near north–south (N–S) plates which dip steeply east (fig. 2A) or west (fig. 2B). Other important orientations (all younger joints) are at 65, 285, 330°. Within the intrusion, estimated at 100–150 m below the roof,

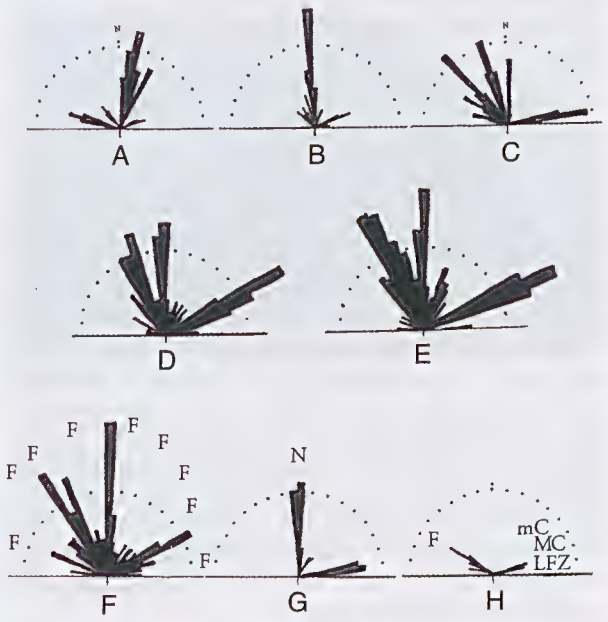


FIG. 2 — Joint characteristics at Single Hill. All characteristics of a typical dolerite intrusion can be assessed. (A) and (B) represent joints (each 100) from two large outcrops of fine-grained dolerite displaying a predominance of platy joints, some of which are curved. N–S joints at (A) dip steeply east while those at (B) dip steeply west. (C) joints (100) with coarse-grained dolerite. (D) indicates all the joints (120) within a single-column cross-section by frequency of occurrence, while (E) indicates the same joints (120) by total length. This shows that joints trending 335°, while numerous, are extended. (F) presents a summary of joint frequencies (320) for many columns. The diagram also suggests the common orientations for column faces (F). (G) displays the joints (66) observed within Fern Tree Group siltstones near site (B) while (H) displays joints (30) observed within Cascades Group/Deep Bay Formation above the roof of the main intrusion.

The orientations of faults, large fracture zones, major contacts and minor contacts are indicated by symbols F, LFZ, MC *or* mC *respectively.*

predominant orientations are 80, 315 and 340° (fig. 2C). In the columnar zone (fig. 2D, E, F) predominant orientations are 0, 65, 80 and 335°, which suggests a unity in orientations overall with local bias according to place in the intrusion. These orientations must also be seen in regional context: major intrusive (discordant) margins trend at about 70–75°, minor margins at 55–60°, faults disrupting the site are oriented at 285–295°, and other penetrative fracture zones are oriented at 80°. Large-scale rift faults, which bracket the Single Hill horst, trend approximately N–S. Joints in the intruded rocks inconsistently reflect aspects of these structures. Both the dolerite and Fern Tree Siltstone (fig. 2A, B, G) from the same area display the same N–S bias. There are very few joints in the Deep Bay Formation rocks (2H) even though extensively metamorphosed, and these reflect fault and contact orientations.

The diagrams do not indicate the most common joint orientation as shown in plate 2 — parallel to the intrusion roof and normal to the columns. Nor is it possible to identify the column faces in these diagrams. It is clear, in the Single Hill situation and almost certainly everywhere else, that many joints have an original thermal origin (as related to contact alignments), and others are associated with more recent faulting and epeirogeny.

Column faces, identified by polygonal form and facetted facing, are found to be oriented at 5–10, 20–25, 35–40, 50–55, 75–80, 285–290, 320–325, 330–335 and 345–350°. All these orientations appear in the rosettes, but some are rare overall and not recorded within the columns or rock mass (20–25, 35–40, 50–55, 320–325, 345–350°), although many contacts reproduce them (50–55, 75–80, 320–325°). Further, some of these orientations yield major faces. It is usual to find that five to seven of the face angles provide major faces and the remainder provide facets or curved, linked surfaces; the selection differs from column to column and few orientations predominate. The association between column face orientations and intrusive margins shows that at least some of the features present in this intrusion are Jurassic in age and control (perhaps older). Since the N–S bias of figure 2A, B, G represents the oldest joint system, it may well be that it also is related to the form of the intrusion and hence Jurassic in age. There are some examples of curvature in these joints. This could mean that the Tertiary rift faulting represents some rejuvenation of older structures.

This evaluation of well-exposed margins, joints, and parts of large and small intrusions shows that it is essential to know the setting and character of the intrusion before any assessment of joints can be made. A simple collation of joints without regard for boundaries or identification of type cannot be used to determine age, type or origin of joints in dolerite.

Review of these exemplary situations shows that any appraisal of the escarpments of the Central Plateau or the Tasman Peninsula must involve inspection of the actual shape of the columns.

Plates 3–6 indicate conditions near Fisher Bluff, Munro Bight and Cape Raoul. Every other situation is similar. Every rock pillar can be traced back from the escarpment and shown to be a four- to eight-sided (most commonly five- to seven-sided) polygon. Plates 1, 4 and 5 show that no gross or systematic joint system extends inboard of the escarpment face, and that joint patterns are defined by primary columnar shapes and other thermal joints within the defined columns. Persistent and continuous fractures do exist but they are the exception, not the rule, and their spacing must be counted in tens to hundreds of metres. The escarpment pillars are usually 1–5 m across (mostly 1–2 m). The polygon faces are often slightly curved and small facets appear on some corners. Each polygon may have about six large faces and up to four very small faces.

The cliff face on the north side of Munro Bight (pl. 3) is composed of jointed pillars which plunge steeply to the south. The surface exposures at the top of the cliff prove that these pillars are columns (fig. 3). This is one of the few sites on the Tasman Peninsula in which the columns stand some degrees from vertical, and their orientation reflects the shape of the intrusion, which is not concordant. The type examples at Single Hill and Mount Nelson (Leaman 1997a) show that column plunge is normal to intrusion margin. Figure 3 also shows the orientations of many hundreds of joints, as well as the column faces which form a minor subset. The major contact (unfaulted) in the area is oriented at about 80° which accounts for many faces and other joints. Many coastal notches are oriented at about 40, 335 and 350°, which are common face and joint orientations. Many cliff edges are aligned 25–35°, also represented by joints in the area. Note that no joint with any of the topographic alignments is generally penetrative and that many orientations are clearly Jurassic in age. Figure 3 does, however, suggest how notches and cliff edges may be defined with or without an additional fracture system. The columnar faces do have an alignment bias toward orientations of about 85 and 330°, and it is hardly surprising if these cliff edge orientations develop as the rock mass is eroded. At least one of these orientations, which produces the cliff face on the north side of Munro Bight, is determined by the intrusive margin. Neither of these two nominally orthogonal orientations represents a penetrative or epeirogenic joint but, where the exposure is poor, they could appear to do so.

The ragged faces shown in plates 4 and 6 could be generated by a regional fracture which has cut across columns but may also be produced by an inherent bias in face angles.

These observations suggest that neither Carey (1958) nor Banks *et al.* (1989) were justified in assigning general tectonic fracturing as the explanation for the columnar appearance. The rock pillars are generally true thermal columns. Further, scale is important. Carey (1958) could recognise (or infer) large fracture systems only at photo scales — but not the column pattern — and concluded incorrectly. It may yet be found that many of the gross trends are, in fact, rejuvenations of orientation bias within the columns and not tectonic, given the suggestive correlation between the face orientations at Munro Bight and the marked clefts along the Bight to Cape Hauy.

Studies of several cliffs have also revealed aspects of thermal history. Many intrusions are multiple and apparently "layered" (e.g. Single Hill, Leaman 1997a). The intrusion at Cape Raoul is such a body. In each case, the columns extend across the textural and compositional variations (pl. 6). Many internal contacts show that previous intrusions were often hot, but already crystalline, with minimal chilled margins. Detailed inspection of joints near layer junctions shows that an hierarchy exists. Some early formed joints do not propagate in the next layer and often contain a mineral fill (calcite, zeolite). Many are platy. The principal columnar joints propagate throughout the entire intrusion independent of layering variations, and this

PLATE 3

View of cliff edge in Munro Bight west of the Monument Lookout. The cliff alignment shown is oriented at about 335° while the general alignment of the cliff is oriented parallel to the main discordant margin (80°).

PLATE 4

Columns and eroded surface near Fisher Bluff, western edge of Central Plateau. Note that the column faces appear rectangular but that no fracture trend can be traced from the scarp into the rock mass. All columns average 2–3 m across and appear to be rectangular (pl. 5).

PLATE 5

Detail of column tops at Fisher Bluff. Note the irregular overlapped pattern of the polygons and absence of regional trends and fractures. Most polygons are five- to seven-sided. Comparable character may be observed on clifftops at Cape Raoul and Munro Bight. At such sites all faces can be inspected, but in normal situations much of the detail is obscured by joint fillings, debris or soil cover. Patchy weathering profiles may also conceal this information.

PLATE 6

"Layered" dolerite on west face of Cape Raoul. Columns are continuous and unaffected by variations in lithology. Cliff is over 200 m high at this point. Columns are typically 2 m wide. The cliff alignment has the appearance of a fracture control but the effect may be due to a column face orientation bias.

behaviour is most clearly demonstrated at site A, Single Hill (Leaman 1997a, fig. 4). These observations confirm that columns form late in the intrusion and cooling cycle, and that polygon formation, once begun, can be imposed on newer injections, provided the injection period spans only a small proportion of the total time required for complete cooling (to below 300° C). One hundred thousand years can be allowed for column formation, and the rate of heat loss is not radically modified by incremental, additional injections while all the material remains warm or partly crystallised (Jaeger 1958).

JOINTING IN OTHER IGNEOUS ROCKS

Several comparable deductions have been made in other igneous rocks (thick lavas and granites). Segall *et al.* (1990) showed, on the basis of dated fillings, that fractures form within large granite intrusions as the rock cools. Common joints in the Sierra Nevada granites are nearly parallel (not forming polygonal systems) in the style of Single Hill (fig. 2A, B). Segall *et al.* (1990) inferred a bias applied by lithostatic or tectonic forces during cooling. Segall & Pollard (1983a,b) and US Geological Survey (1984) suggested that faults (or master fractures) may evolve from original joints where some orientation bias already exists. The Munro Bight and Cape Hauy dolerite provides supporting evidence for such a concept. The Munro Bight joint pattern (e.g. fig. 3) matches the irregular polygonal form (non-hexagonal) in the classification of Pollard & Aydin (1988).

The variation in four- to seven-sided character, and the apparent four-sided visual appearance (noted near margins at Ridgeway, Single Hill and inferred by Banks *et al.* 1989 overall), may be consistent with observations in thick flows, where there is often a general change in form from four- to six-sided character depending on position within and

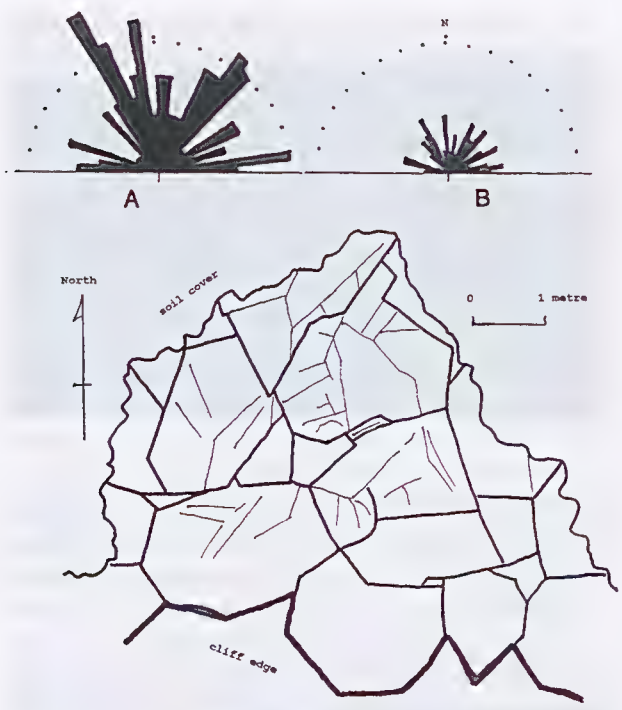


FIG. 3 — Joint patterns on north side of Munro Bight, west of the Monument Lookout. (A) displays all the joints (160) in the region of the cliff edge section while (B) presents only those joints (52) recognised as column faces. The map indicates a typical joint pattern in plan. Note the way in which even this short section of cliff face has developed a hackly but generally systematic alignment just south of east. Other clefts in this cliff emphasise the face alignments at 40 and 330°. Note that there are no cross-cutting fractures in this exposure.

thickness (Aydin & DeGraff 1988). DeGraff & Aydin (1993) related the size of columns and spacing of all joints to the rate of temperature change. It is not yet clear if this is true of Jurassic dolerites, but depth of burial at the time of intrusion may be important since there is a difference in overall joint character between dolerites intruded into Permian rocks and those intruded into Late Triassic rocks (Leaman 1997a).

THE TESSELLATED PAVEMENT

Banks *et al.* (1989) outlined the history of visitation to, appreciation of and publication about the jointed shore platform at Lufra, Eaglehawk Neck (site D, fig. 4). The site, now protected and visited by thousands each year, is a representative shore platform within the Pirates Bay region. A smaller pavement nearer Clydes Island (also noted by David & Browne 1950) is actually a finer and more compact example (site C, fig. 4).

The term "tessellated" is here taken to refer to the fine patterns exposed (*Oxford English Dictionary*) and not to any direct affinity with tiles. There are many subtle variants within the patterns which are not tile-like. The two fine pavements are not unique, but inspection of the coastline does show that good examples of the possible patterns are rare, and it is clear that early visitors were impressed by the quality of display at Eaglehawk Neck. Plate 8 exemplifies the finest pattern.

The pavements around Pirates Bay, all in members of the Permian Malbina Formation (Clarke 1989), have been formed since sea levels stabilised a little more than 6000 years ago. There are indications of an eroded, higher level surface about 1 m above present mean sea level. The Permian rocks are interbedded pebbly siltstones and sandstones. Individual beds tend to be compositionally uniform and up to 600 mm thick, but some are very thin and fissile. Each bed of these poorly sorted rocks is fairly uniform overall but is individually distinctive in both texture and grain size.

Microtopography of the Pavements and its Origin

Banks *et al.* (1989) outlined previous theories for the origin of the tessellations (pl. 7); tile pans (pl. 7), loaf-of-bread (pl. 7 front) and pane-of-glass (part pl. 8) effects. The finest form (pl. 8) has the appearance of dressed stone with a finely chipped margin and a coarsely chipped interior. Banks *et al.* and the present writer concluded that intertidal coastal abrasion, coupled with salt infiltration and expansion upon crystallisation, can explain all effects, including the spongy surface textures and elephant-skin weathering observed. Elephant-skin weathering may also be related to whole rock changes upon weathering, or local expansion and contraction due to wetting and drying. This salt-based weathering process steadily increases porosity and leads to loss of original cements or matrix. Most pitted surfaces reflect this action. Most change occurs about joints, which act as conduits, vertically and laterally, for fluid flow, and wall rock alteration is greatest along them. Alteration distance from the joints varies across the site and clearly depends on changes in porosity effected by water penetration and the particular properties of the bed. This process commonly leads to engravure along the joint, as cement or matrix is removed and grains can be separated. Where water can pass freely or stand, the etched zone is widened and flattened to produce the classical "dressed stone" pattern edge margin (pl. 8). The relationship between joint capacity (to transfer fluid), intertidal level, actual rock composition and porosity, rock dip (which controls rates of infiltration or evaporation) and prior fluid history (which may have variably altered primary properties) controls the rate of rock destruction and hence the particular style of weathering which results. Exceptional situations arise where chemical exchange occurs, and iron oxides can be precipitated. Iron oxides tend to act as a firm cement and filling and are also more resistant to further physical or chemical weathering than the unaltered or partly expanded host rock.

All processes and exchanges are clearly modern. These rocks may never have contained a cement, as such, but compression of the fine matrix on compaction may have achieved a comparable result. Iron sealing may be restricted to the joint itself or be evident in colouration up to 50 mm from the joint. All joint sets are affected by all processes; thus, iron oxides may be found in any joint set at any location. Only a small proportion of joints is iron-sealed or modified at any site. Joints filled with iron oxide are more resistant, and the selvedge of rock adjacent to them may be elevated; this contributes to the formation of the panes-of-glass effect when water can rest on the blocks.

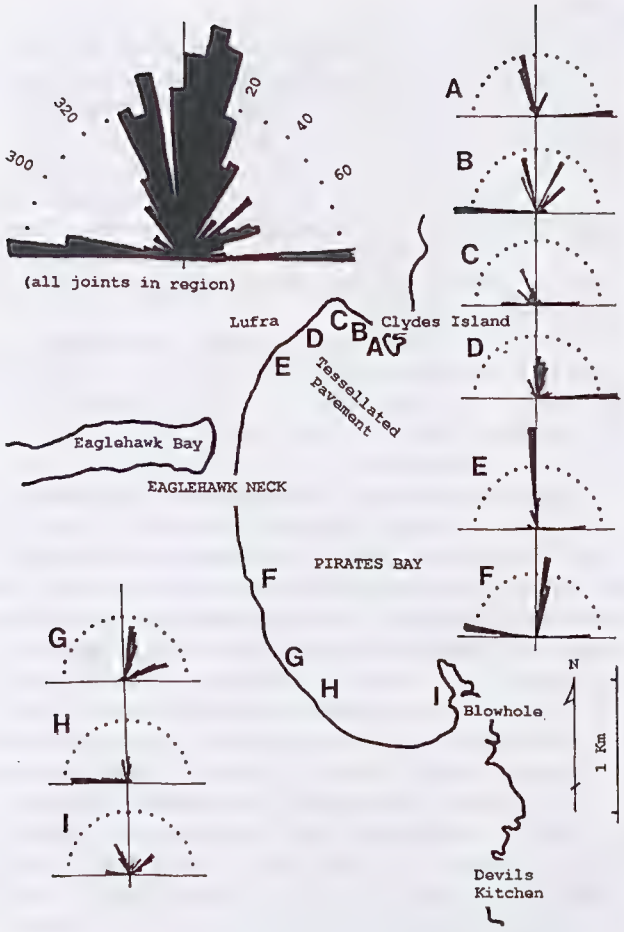


FIG. 4 — Location of jointed pavements in Pirates Bay region. Each rosette represents 100 joints (except C – 170 joints) for a pavement segment. The rosettes have been plotted by 5° intervals and marked for each 10°. The markings are provided at 20% measurement weight. The large rosette is a compilation of all sites.

PLATE 7

Part of mini pavement (site C, fig. 4) at Pirates Bay. Note the change in character from bed to bed. Bed in foreground shows loaf-of-bread character. Joints on underlying bed are acute to main trend on upper layer and conjugate set is absent. View looking west. Joints facing the camera are 200–300 mm apart.

PLATE 8

Typical example of Tessellated Pavement (site D, fig. 4), much as illustrated by many authors. Note the tile format, etched joints and some pane-of-glass effects. Observe that joints extending from left to right are extended, while those facing away from the camera are much more segmented. Note the single large, braided fracture which disrupts all other features (and penetrates all beds). View looking north.

Inspection of many pavements has also revealed the rarity of the true dressed-block effects (pl. 8). Such effects are only well developed near sites B and D (fig. 4).

The Origin of the Joints

While this discussion suggests the nature of the origin of the present display, it does not resolve the issue of the origin of the joints themselves; whether these are formed as part of the weathering cycle or control it.

The nature of the joints

All joints, even newly-formed features, are well defined physically (pls 7–10).

Several features may be noted at the Tessellated Pavement.

(1) Spacing or orientation of parallel joints is not clearly related to grain size or bed thickness but may vary between 100 and 750 mm in most beds regardless of character. The spacings are typically between 200 and 500 mm in siltstones.

(2) Joint terminations are complex (pl. 9), displacements are negligible and not systematic, and joints break pebbles of all sizes. Joints are developed synchronously.

(3) Many orientations are recognisable in newly formed elephant-skin cracks, and these can be shown in various stages of interconnection to yield new fractures within existing tessellations.

(4) At least two joint sets occur in all layers, but some beds contain at least one additional joint. All joints are subvertical.

(5) Some subhorizontal joints are visible in more fissile beds, and only a small proportion of joints of any orientation extend through any bedded sequence.

(6) Not all joints or members of any joint set consistently affect more than the exposed bed (pls 7, 10). Many joints are restricted to a single bed.

(7) Most joints, including newly formed surface cracks, open upward and show no suggestion of an incipient fracture deeper within the bed affected.

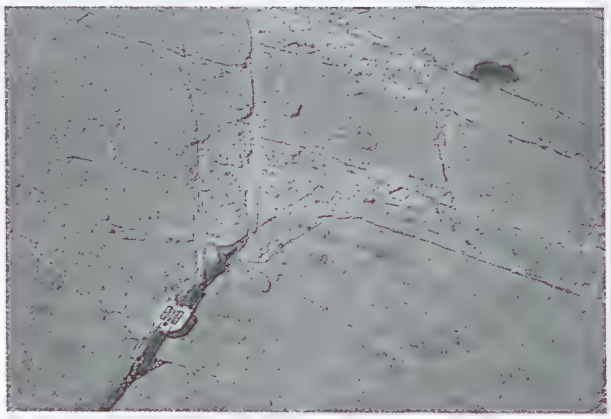


PLATE 9

Example of interrelation of joint systems (site I, fig. 4). Regular patterns are developed in each subzone about the complex triple point. Many small offsets have been recorded along each joint set at every site; yet no consistent pattern of age or relationships can be assigned. Features such as this triple point show that all fractures are contemporaneous and grow intermittently as an entire group with exposure and modern weathering (with consequent expansion of the rock mass). View looking east.

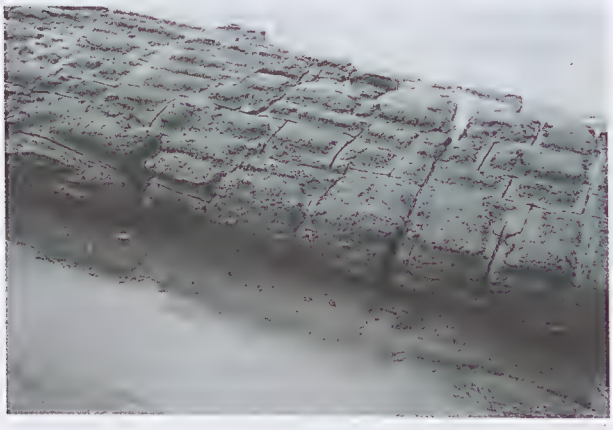


PLATE 10

Part of pavement at site E (fig. 4). Note that only one in three or four of joints facing the camera actually passes into the underlying bed. Many other sympathetic joints are shorter or within tessellations. View looking south.

The local structural background

The rocks exposed around Pirates Bay are, in regional context, virtually flat-lying; dips rarely exceed 3° although strike is variable. There is no system to dip variations around the bay; most changes may be due to minor bed rotation near faults — there being several small faults in the bay area, especially north and east of Lufra and the main tessellated pavement. It has been suggested that a small anticlinal fold is present at the north end of the bay and that the bisectrix or joint orientation is consistent with this (Banks *et al.* 1989). It is not possible to evaluate these explanations due to lack of exposure.

Joint directions

Banks *et al.* (1989) stated that the common joint directions are about 330 and 75° with a bisectrix at 295°. An additional joint (15°) was found in some beds. Dr M. Banks (1996, pers. comm.) revised these details as follows: 0, 13, 89°, bisectrix 51°. These latter directions, but not those published, can be replicated (site D, fig. 4). Further examination suggested that the results might be site specific. Carey (1958, 1976), however, implied that the joint system was regular, regionally coherent, mirrored by the dolerite joint system and penetrative.

The first part of this paper has shown that significant parts of the dolerite joint systems are predominantly thermal in origin while preliminary inspection at the pavement suggested that many joints may be neither coherent nor penetrative as implied by Carey (1958: 229).

Detailed measurements, therefore, were undertaken at nine platforms around Pirates Bay, in order to fully test Carey's (1958) proposition and the comments of Banks *et al.* (1989). Approximately 1000 joints were measured; for orientation, continuity, character and bed penetration. The results are summarised in figure 4 and table 1. Continuity is defined as the minimum continuous visible length of joint. Not all joints are fully exposed; many pass into cliffs or to seaward and many pavement joints provide an illusion of length, although present as relatively short segments (1–3 m) not connected to other joints of similar orientation. Tessellations may appear surprisingly regular or perfect from a distance and yet be found to be based on quite irregular joint associations, when examined closely. It is the consistency of interlocking trends, not the orthogonal continuity of particular fractures or joint pairs, which produces the overall effect (pl. 8).

Observations of joints has included a description of the type of breakage; some orientations appear as simple, planar breaks, others are compound fractures (centre of pl. 6, trending from the camera) and may feather or include small *en echelon* fractures in a narrow band. Some joints are curved, and a range of surface characters may be observed; most are straight with smooth surfaces.

Bed penetration was checked for all joints which extended across a platform or bed edge, or into a cliff face.

Measurements were made on a segment of each platform within a 15 m radius of a randomly selected point. All joints longer than 300 mm were measured. It should be noted that many smaller, isolated fractures do exist. Therefore, any simple correlation based on frequency of occurrence may be misleading, since the measured area may contain only 20 joints at one pronounced orientation and 60 at another (as in pl. 8). The effect may still be tabular, but the continuity, character and penetration factors may be quite different. The rosettes of figure 4 should only be used to suggest dominant orientations and not necessarily significance or importance of trend. Each rosette is expressed in terms of percentages of joints within the sampled area.

Figure 4 shows that there is great variability in trends around Pirates Bay. There is no regional coherence other than the general presence of a near east–west (E–W) element. North–south elements are much more patchy and inconsistent. This conclusion can be established by consideration of scale and character (table 1). A compilation of all measurements is shown in the large rosette in figure 4. The dominant trend is E–W with subsidiaries at about 10° and 345° and a bisectrix around 50°. This compilation

TABLE 1
Summary of characteristics of joints around Pirates Bay*

Platform site†	0–15	15–30	50–65	85–95	300–310	335–350
			(joint orientation package)			
A		c3common		a5some		b0.5rare
B		c4common		a2rare		b1.5rare
C1				a10rare	c0.3rare	b4rare
C2	a4rare			b4rare	c1.5rare	
C3	c0.7rare			a3rare	c1rare	b9rare
D	b4rare			a12some		c0.7rare
E	a1rare			b5some		c0.5rare
F	a9some			b12common		
G	a3some		b8some	c0.6rare		
H	b1some			a9common		c10common
I			a10common	b3rare		c1.5rare

* Each comment is in three parts, XnY.
X is a measure of the relative dominance of the joint: a = very common, b = less common, c = not common.
n is the average length in metres of joints of that orientation (minima for long joints).
Y is a comment to indicate how often joints of the given orientation pass continuously between beds:
rare implies that the joint is usually confined within a bed;
some means the joint set may occasionally continue into the adjacent bed;
common means that the joint set usually continues into the adjacent beds.
Joint spacing is not diagnostic.
† Sites as in figure 4; characteristics of individual beds are presented for site C.

tends to stress the N–S character regionally and yet, seen in detail as subsets, it is neither universal nor consistent. This suggests that joint assessments which do not consider the source of data, and variations within it, might be misleading. No geographical domains can be constructed from the measured sites, although variations between sites A and E might be related to N–S faulting. Such fault-controlled patterns cannot be matched on the southern side of the bay, a fact which might reflect distance or the presence of sub E–W faults south of site E. Major N–S fractures and small faults can be observed parallel to the coast south of site I and yet there is no reflection of this orientation in data from this site.

Table 1 shows the "classic" pavement to be both typical and atypical. It contains the three most observed trends (within a narrow envelope) but not in consistent proportion or importance. Few of these trends are consistently penetrative, although casual inspection of adjacent cliff faces might suggest otherwise. Many joints are only present on the upper surfaces of beds or exposures, with no suggestion of any expansion of pre-existing cracks — indicating a weathering and relaxation process for their origin. Only compound, complex joints made up of a net of interwoven smaller fractures (such as facing camera in pl. 8) are truly disruptive and these may be the only true epeirogenic joints; their spacing is irregular.

The joint trends observed may be contrasted with fault or gulch orientation. Major faults and fractures in the region are oriented at either 355–360° or a stepped combination of 80–90° and 65°, and the overall effect is that of structures trending a little north of east north of Eaglehawk Bay or a little south of east south of Eaglehawk Bay. Eaglehawk Bay represents a gross feature of this type. Where large E-W structures can be inspected on shore platforms, each is seen to consist of long fractures extending E–W joined or offset by shorter fractures oriented at 65°. Such offsets are noticeable at sites B, D, G and I. This behaviour is consistent with dextral shear and might well locally yield sub N-S fractures.

Joints and regional structures

Regional faults (Leaman 1997b) occur with trends at approximately 5, 65, 290, 310, 330 and 350°. The principal structure in the region, a concealed granite margin and associated dolerite feeder, trends approximately N–S beneath the Eaglehawk Neck area. Structures near and above this margin were demonstrably active during Jurassic and Tertiary times (Leaman 1997b) and may have been active during, or soon after, deposition of the Permian cover rocks. It is possible that local thickness changes within the Permian rocks are related to such activity, and stress variations would have been imposed on the sequence, due to subsequent compaction.

The absence of any major major E–W faults, the likely shear character of E–W features, and the possible effect on production or reopening of N–S fractures and association of feeders suggest that most of the structural controls are ancient but may well be subject to modern rejuvenation. The sub N–S joint system is almost certainly related to stresses which were imposed soon after deposition and which continue to re-activate the granite margin. Several small N-S trending faults can be found south of Pirates Bay near the coast. Any stresses may have been moderated during time, due to continental margin rifting and uplift throughout the last 70 Ma, or to pulsed compressions of the type described by Davidson (1997). Recent (c. 1985) seismic activity near Bream Creek was focussed on a portion of the granite margin, and the shape of the eastern coastline of Port Arthur to the south is also consistent with long-term, minor activity. No large-scale structures, other than dolerite intrusions, have been observed along this entire marginal zone. The E–W system is certainly regional as described above (although no known fault has this orientation in this area) and has been recorded (at about 80°) in many data sets covering eastern Tasmania (e.g. Leaman & Richardson 1990). Each erosional gulch along the coast has formed where several E–W fractures are grouped. All other regional trends, as listed above, occur on the Forestier Peninsula, but most are unknown in the Pirates Bay area.

Joint spacing was noted at all sites but was found to be a non critical criterion or descriptor. Most joint sets, regardless of continuity or appearance, present similar spacing ranges (100–500 mm for well-developed character; 10–100 mm for incipient character). Only complex systems (described above, pl. 8) or groups of E–W fractures may offer useful spacing data, but such compound systems are rarely less than 10 m apart and may exceed 50 m separations.

How old are the joints?

Many joints are now in formation as a result of unloading by erosion and weathering. These are present as splinters or isolated fractures within tessellated blocks. Elephant-skin texture occurs at various scales on many block surfaces. The formation of minor fractures must represent whole rock expansion and not simply regional stresses; yet the orientations are consistent with, or are affected by the local, developed joint sets. This implies some degree of prestressing within the rock mass. New joints grow to connect and expand the tessellation pattern, even as erosion levels and removes coastward portions of beds.

Branagan & Cairns (1993) have described similar surfaces in Triassic sandstones. The fractures rarely extend more than 200 mm into the rock and were inferred to be due to weathering and erosion processes on an old landscape. Thermal expansion/contraction was proposed as the likely cause, the presence of an expandable clay an additional swelling factor. It is not known which clays, if any, are present at Pirates Bay, but salt-related alteration and swelling processes are active.

The small pavement at C (fig. 4) was examined in greater detail and all joints measured were identified by bed. Three beds were inspected and the summation of all joints at the site is given in figure 4. Each bed could be described as a pebbly siltstone and not readily distinguished from its companions. Some striking differences (table 1) were noted and some of these can be seen in plate 7. Two beds (C1, C3) lack the near N–S joints, while all beds preserve the E–W joints. Beds C1 and C2 record trends about 300°, while beds C1 and C3 reflect trends about 340°. Only bed C2 carries N–S and NE trends. This variability, lack of vertical continuity and also change in spacing (evident in the plate) and length show that lithology and the physical characteristics of the beds are important. There is no suggestion that these rocks were stressed and fractured when confined and buried to produce a coherent regional, tectonic fracture system of the type implied by Carey (1958, 1976).

Many joints pass from subvertical in the local bed to subhorizontal near the first bedding parting, which, also, is usually fissile and expanded by weathering, alteration or relaxation. There is little sense in which this rock sequence could be said to have been stressed and fractured as a package; nearly all effects are surficial.

Finally, it can be shown that, in any given pavement, the ternary joint grouping (few pavements approach binary patterns, although the finest tessellations occur where this situation is approximated) develops concomitantly (pl. 9). Various patterns of offset and movement can be assigned on any pavement, but none are consistent either within a pavement or with other pavements. All observations on the pavements are consistent only if joints have grown synchronously within the exposed weathering environment. Although the pavement joints display more regularity than those described by Branagan & Cairns (1993), the origin must be similar. The regularity, persistence and recurrence of orientations suggests a prestressed condition controlling each joint set. The basic stressing, active since at least the Permian, is a fundamental E–W shear with a derivative N–S component. Most joints form only on unloading (as suggested by Banks *et al.* 1989) in such a stress field, with results modified by bed thickness, strength and susceptibility to weathering.

The much appreciated, delicate block pavements — with their variations in decoration — are relatively rare and must reflect bed composition and particular, chemical weathering processes, or perhaps rate of application of process.

CONCLUSION

Examination of jointing at the well-known coastal features on the Tasman Peninsula has shown that there is no simple ruling, regional scheme.

Persistent regional joints are relatively rare, although present in the dolerite of the high cliffs and on the siltstone shore platforms. Such joints are widely spaced; commonly at 2 m to more than 50 m but consistent in orientation. These are approximately N–S and E–W near Pirates Bay, but it is difficult to judge consistently whether topographic features truly reflect regional joint systems elsewhere.

For example, the dolerite cliffs are dominated by true columnar joints of thermal origin, disrupted in places (and apparently) by more regional tectonic fractures. The primary columns approach hexagonal ideals and are of similar size, regardless of position within the intrusion. Detailed inspection of many outcrops, whether at clifftop, in ravines or on shorelines, shows that, irrespective of irregular terrain or uneven presentation of surfaces, these thermal forms can be identified. Many other lesser thermal or tectonic fractures may attract the eye of the observer and falsify the impression. Review of sites suggests that some topographic alignments have been produced by selective erosion due to slight

biasses in the orientation of column faces, even though there is no actual penetrative fracture. It is possible that regional assessments might infer such fractures when none exist. Observations at Single Hill and Munro Bight show that near-orthogonal patterns apparently can result from primary joint bias. Such a bias in thermally generated joints might well have regional control (crustal controls on feeders, stresses or intrusion form), and the effect will then be rejuvenated. Carey's (1958, 1976) conclusion about regional character might then be valid in these terms, but his implication that the visually striking columns were themselves shaped by a regional, orthogonal joint set of tectonic origin is not. Hale (1958) essentially made this point, and Carey (1958), working at a different scale, did not recognise the disguised character of visual interactions involved. His mistaken view has prevailed and persisted into more recent literature. Hills (1963) was quite correct to suggest that the Tasmanian escarpments offer superb examples of true columnar form.

The study has also shown that collection of joint measurements, without due regard to contacts, known faults, recognisable column faces and transgressive boundary orientations, may well be meaningless or very difficult to interpret in a rock like dolerite. Further, columns may only be defined reliably on the basis of basic morphology, confinement of other fractures and curvature of faces separating facets.

The formation of tessellated platforms and the visually attractive patterns requires near horizontal bedding and an extensive weathering process. Most joints on such platforms at Pirates Bay are surficial in origin, grow downward and are "modern" developments. The joints do appear to be the result of application of regional stresses to a rock package unloaded by uplift and exposure. There is an element of prestressing in the rocks, which leads to bias upon unloading and weathering. Some regional and tectonic joints do exist, but these are not directly responsible for, nor related to the tessellations, and most disrupt the patterns. Near E–W fractures are regionally dominant, and many important coastal landforms or alignments are controlled by them although negligible displacement is associated with these features. An underlying dextral shear in the Lufra area, whose position is now marked by Eaglehawk Bay, is thought to rejuvenate fundamental N–S components.

Weathering processes are crucial to development of surface cracking and ultimately, within the subtly imposed stress field, linkage of cracks. These grow downward into and along the beds as the weathering process acts upon them. The surface featuring of each formed block is the combined result of physical and chemical weathering processes. Fracture origin of this style, with a fundamental applied bias, can lead to an apparent sub-orthogonal regional pattern which mirrors the underlying shear cause.

In these terms, the joint development in both dolerite intrusions and pavements is comparable, with a fundamental in-built bias related to pre-existing structures, followed by selectively eroded bias to produce topographic features — and apparent regional fracture grain. Such an explanation would account for the clear differences in joint patterns in adjacent areas (Pirates Bay, Hauy–Munro Bight) and other areas (including Single Hill). A comprehensive review of joints in southern Tasmania is needed to determine whether Carey's (1958, 1976) suggestion is valid regionally, but the dolerite cliffs and pavements of the Tasman Peninsula suggest that many gross fracture patterns may result from selective erosion determined by original alignment bias and not a regular, imposed fracture set.

ACKNOWLEDGEMENTS

I am grateful for useful discussions during the 50th anniversary celebrations of the Geology Department visit to the Tessellated Pavement in 1996 and subsequently with Dr M.R. Banks. Field assistance was provided by Marcia Solomon.

REFERENCES

Aydin, A. & DeGraff, J.M., 1988: Evolution of polygonal fracture patterns in lava flows. *Science* 239: 471–476.

Banks, M.R., 1998: Changing visions of our mountain. *In* Terry, I. & Evans, K. (Eds): *HOBART'S HISTORY: THE FIRST TWO HUNDRED YEARS. Pap. Proc. Conf. Prof. Hist. Assoc. Tasm. 4 Oct. 1997*: 7–18.

Banks, M.R. & Leaman, D.E., 1999: Charles Darwin's field notes on the geology of Hobart Town — a modern appraisal. *Pap. Proc. Roy. Soc. Tasm.* 133(1): 29–50.

Banks, M.R., Colhoun, E.A., Ford, R.J. & Williams, E., 1989: A reconnaissance geology and geomorphology of the Tasman Peninsula. *In* Smith, S.J. (Ed.):*IS HISTORY ENOUGH? PAST, PRESENT AND FUTURE USE OF THE RESOURCES OF TASMAN PENINSULA.* Royal Society of Tasmania, Hobart: 7–23.

Branagan, D.F. & Cairns, H.C., 1993: Tesselated Pavements in the Sydney Region, New South Wales. *J. Proc. R. Soc. NSW* 126: 63–72.

Carey, S.W., 1958: Note on the columnar jointing in Tasmanian dolerite. *In DOLERITE, A SYMPOSIUM.* University of Tasmania, Hobart: 229–230.

Carey, S.W., 1976: *THE EXPANDING EARTH.* Elsevier: 488 pp.

Clarke, M.J., 1989: Lower Parmeener Supergroup. *In* Burrett, C.F. & Martin, E.L. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ. 15*: 293–309.

David, T.W.E. & Browne, W.R., 1950: *THE GEOLOGY OF THE COMMONWEALTH OF AUSTRALIA. Vol.2.* Edward Arnold, London: pl. 76 (opp. p. 113).

Davidson, J.K., 1997: Synchronous compressional pulses in extensional basins. *Mar. Petrol. Geol.* 14: 513–549.

DeGraff, J.M. & Aydin, A., 1993: Effect of thermal regime on growth increments and spacing of contraction joints in basaltic lava. *J. Geophys. Res.* 98: 6411-6430.

Forsyth, S.M., 1984: *OATLANDS, TASMANIA. Tasm. Dep. Mines Geol. Atlas* 1:50000 Series. Explanatory Notes. Sheet 68 (8313S).

Hale, G.E.A., 1958: Some aspects of jointing and decomposition in Tasmanian dolerites. *In DOLERITE, A SYMPOSIUM.* University of Tasmania, Hobart: 184–196.

Hergt, J.M., McDougall, I., Banks, M.R. & Green, D.H., 1989: Jurassic dolerite. *In* Burrett, C.F. & Martin, E.L. (Eds): *GEOLOGY AND MINERAL RESOURCES OF TASMANIA. Geol. Soc. Aust. Spec. Publ. 15*: 375–381.

Hill, P.A., 1964: Curviplanar (radial, bow-tie, festoon) and concentric jointing in Jurassic dolerite Mersey Bluff, Tasmania. *J. Geol.* 73: 255-270.

Hills, E.S., 1963: *ELEMENTS OF STRUCTURAL GEOLOGY.* Methuen, London: 483 pp.

Holmes, A., 1965: *PRINCIPLES OF PHYSICAL GEOLOGY.* Nelson, London: 1288 pp.

Jaeger, J.C., 1958: The solidification and cooling of intrusive sheets. *In DOLERITE, A SYMPOSIUM.* University of Tasmania, Hobart: 77–87.

KELLEY, V.C., 1987: Joints and fractures. *In* Seyfert, C.K. (Ed.): *THE ENCYCLOPEDIA OF STRUCTURAL GEOLOGY AND PLATE TECTONICS. Encycl. Earth Sci. Ser.* 10. Van Nostrand, New York: 876 pp.

LEAMAN, D.E., 1972: The engineering properties of Tasmanian dolerite with particular reference to the route of the Bell Bay Railway. *Tech. Rep. Dep. Mines Tasm.* 16: 148–163.

LEAMAN, D.E., 1978: Some thoughts on dolerite intrusions with particular reference to marginal features. *Rep. Geol. Surv. Tasm.* 1978/30.

LEAMAN, D.E., 1997a: Features of Jurassic dolerite intrusions at Cape Surville, Lynwood, Single Hill and Mount Nelson, Tasmania. *Pap. Proc. R. Soc. Tasm.* 131: 13–20.

LEAMAN, D.E., 1997b: Gravity survey and structure of the Forestier Peninsula, Southern Tasmania. *Pap. Proc. Roy. Soc. Tasm.* 131: 77–84.

LEAMAN, D.E. & RICHARDSON, R.G., 1990: Tasmanian crustal features. *Abstr. 10th Australian Geological Convention, Hobart*: 100–101.

POLLARD, D.D., & AYDIN, A., 1988: Progress in understanding of jointing over the past century. *Bull. Geol. Soc. Am.* 100: 1181–1204.

SEGALL, P. & POLLARD, D.D., 1983a: Joint formation in granitic rocks of the Sierra Nevada. *Bull. Geol. Soc. Am.* 94: 563–575.

SEGALL, P. & POLLARD, D.D., 1983b: Nucleation and growth of strike-slip faults in granite. *J. Geophys. Res.* 88: 555–568.

SEGALL, P., MCKEE, E.H., MARTEL, S.J. & TURRIN, B.D., 1990: Late Cretaceous age of fractures in the Sierra Nevada batholith, California. *Geology* 18: 1248–1251.

U.S. GEOLOGICAL SURVEY, 1984: A summary of geologic studies to January 1, 1983 of a potential high-level radioactive waste repository site at Yucca Mountain, Southern Nye County, Nevada. *USGS open file report* 84-792. USGS Denver, Colorado: 103 pp.

(accepted 5 July 1999)

TASMANIA'S AQUACULTURE INDUSTRY: A TEN-YEAR REVIEW OF IMPROVED DIVING SAFETY

by David Smart, Sean Rubidge, Peter McCartney and Corry Van Den Broek

(with four tables, two text-figures and two plates)

SMART, D., RUBIDGE, S., MCCARTNEY, P. & VAN DEN BROEK, C., 1999 (31:x): Tasmania's aquaculture industry: a ten-year review of improved diving safety. *Pap. Proc. R. Soc. Tasm.* 133(1): 77–83. ISSN 0080–4703. Diving and Hyperbaric Medicine Unit, Royal Hobart Hospital, GPO Box 1061 L, Hobart, Tasmania, Australia 7001.

Tasmania's marine finfish aquaculture industry has developed from humble beginnings in 1986 to become a leading export earner for the state. Marine aquaculture is diving intensive, and divers have made a significant contribution to product quality. The early years of the industry were hampered by significant levels of diver morbidity due to risky diving activities. This ten-year review outlines the major improvements in safety which have been achieved by broad-based changes to diving training, operations and procedures. The number of divers treated annually for decompression illness has fallen from 5.5 per 2100 dives in 1988–90 to 0.5 per 8768 dives in 1996–98. The industry now has a decompression illness incidence of 0.57 cases per 10 000 dives and is in line with world's best practice.
Key Words: marine farms, aquaculture, diving, bounce diving, yo-yo diving, safety, Tasmania, Atlantic salmon.

INTRODUCTION

Tasmania possesses a rich maritime heritage. Since European settlement, the Tasmanian economy has been reliant on its close links with the sea for trade. The unpolluted waters off its coastline support a substantial wild fishing industry. Tasmanians have always enjoyed access to quality seafood. Until the 1970s, wild fisheries were the only significant source of revenue from fishing in the State. A natural progression of the Tasmanian's close relationship with the sea has been the development of marine aquaculture. After initial success with oyster and mussel farming in the 1970s, Atlantic salmon farming commenced in 1986. More recently, marine farming ventures have explored scallop, abalone and striped trumpeter aquaculture. The aquaculture industry is a major contributor to Tasmania's economy, now producing 35% of total fisheries value of $213.9 million (ABARE 1998). From small origins, the marine finfish aquaculture industry grew to employ over 500 people directly in 1997, producing exports worth $64 million (Tasmanian Salmonid Growers Association 1997, ABARE 1998).

Atlantic salmon farming and ocean trout farming are the main sectors of the aquaculture industry which employ divers. Divers contribute substantially to the quality of these fish, which obtain premium prices on world markets. The fish are farmed in floating pens up to 120 m in circumference, which enclose the fish in a cylindrical net suspended from the surface (pl. 1). Pens vary in size, depending on the type of fish farmed and the size of the farm's operations. An aerial photo of a typical lease is shown in plate 2. Divers in the marine aquaculture industry undertake many roles including maintenance of mooring lines and farm perimeter nets, supervising the setting of fish pens, and undertaking checking and repairs of individual fish pens with removal of dead fish from the pens. In addition, they perform many "land-based" activities. In 1990, two of the authors provided an overview of the industry and described how salmon were farmed from smolt to the finished product bound for interstate and international markets (Smart & McCartney 1990). The industry is further described elsewhere (Tasmanian Salmonid Growers Association 1997).

PLATE 1
Diver entering a typical aquaculture pen.

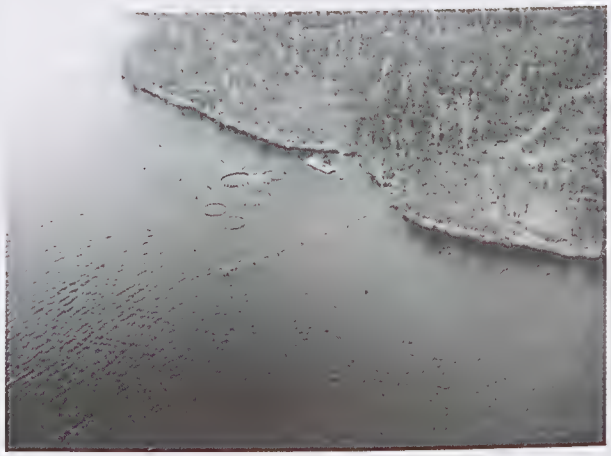


PLATE 2
Aerial photo of an aquaculture lease showing perimeter net around circular fish pens.

The 1990 study by Smart and McCartney found significant levels of diver morbidity occurring in Tasmania's fledgling aquaculture industry, due to high risk diving practices (table 1). Land-based activities also had some impact on levels of post-diving morbidity.

In 1990, episodes of decompression illness (DCI) from the aquaculture industry were unacceptably high. Despite employing only 6.2% of the professional divers in Tasmania, the industry produced 47.8% of the treated cases of DCI at the State's hyperbaric facility at the Royal Hobart Hospital (Smart 1994). In 1990, limited recording of diving activities created uncertainty about the number of dives undertaken in the industry each year. An estimate of 2100 dives per year, based on verbal reports of diving activity occurring at the time, was available to calculate the incidence of DCI.

A major concern identified by the 1990 study was that very few of the divers had training specific to the industry, and 44% of the injured divers had no diving experience, training or qualifications prior to commencing work as divers (Smart & McCartney 1990). This had two potentially serious effects: not only were the diving practices high risk, but the individuals employed as divers lacked the skills and knowledge to recognise safety hazards as they undertook their daily work. The type of diving required by the industry created a further difficulty. Most divers were undertaking multiple descents and ascents in and out of the shallow fish pens (termed "bounce diving" or "yo-yo diving"), and there were no known diving tables to cover this type of diving. Bounce diving was considered to be higher risk for DCI than standard "square profile" diving, involving a single descent then ascent (Douglas & Milne 1991). This higher level of risk was supported by cases of DCI occurring in aquaculture divers who had undertaken all of their dives in less than 9 m (Douglas & Milne 1991). During 1990 and 1991, there was a strong push from the Tasmanian industry, union representatives and diving medicine specialists to improve diving operations within the industry and to protect and maintain the health of its divers. Cooperation between industry participants resulted in significant changes to many areas including diver training, operations, equipment and emergency procedures.

TABLE 1
High risk dive practices among Tasmanian marine fish farm divers in 1990*

1. Diver training
   (a) inadequate or inappropriate;
   (b) almost 50% with no training;
   (c) lack of specific training for the industry.

2. Equipment
   (a) hookah used at excessive depths (>30 m);
   (b) no safety reserve cylinders;
   (c) inadequate thermal protection (5 mm thick wetsuits in 10°C water);
   (d) limited use of specialised underwater tools.

3. Equipment Maintenance
   (a) no maintenance schedules;
   (b) tampering by untrained personnel;
   (c) incorrect oil and filters in compressors;
   (d) saltwater in regulators;
   (e) no air purity standard maintained.

4. Safety procedures
   (a) no protocols for emergencies;
   (b) no backup diver;
   (c) no training for accidents;
   (d) no oxygen or first aid equipment or protocols;
   (e) no diver to surface communication.

5. Dive schedules and profiles
   (a) no logs of time/depth;
   (b) no depth gauges;
   (c) minimal consultation with tables;
   (d) multiple (20–50) bounce dives at depths up to 8 m;
   (e) deepest dives performed last;
   (f) missed safety stops.

6. Other practices
   (a) "Vaulting" the salmon pen;
   (b) Heavy physical work performed after the dive;
   (c) Diving with respiratory tract infections.

* Identified by Smart & McCartney (1990).

AIM

The aim of this paper was to review changes in the diving operations of the aquaculture industry, over a ten-year period from 1/7/1988 to 30/6/1998. We also aimed to assess the safety outcomes of changes to diving practices.

METHODS

A longitudinal review of ten years of diving activity within the aquaculture industry was conducted, assessing a number of factors:
(1) diver participation;
(2) evolution of diving practices;
(3) major episodes of morbidity due to DCI.

This review used information collected from the field, surveys of participants in the diving operations, and the treatment database of the Hyperbaric Medicine Unit at the Royal Hobart Hospital (RHH). We stratified the study into five periods, each of two years. The ten-year period was chosen because it spanned the time during which most of the diving activity has occurred in the industry. It also covered the period during which substantial changes in training and work practices were made from within the industry. The selected ten-year study period overlapped with the original work of Smart and McCartney, with the exclusion of the months of April to June 1988.

We selected the number of decompression incidents requiring treatment at the RHH as our principal outcome measurement. Since the RHH receives all decompression emergencies for the State of Tasmania, this allowed us to capture all *treated* cases of DCI. Information relating to decompression episodes was readily accessed from the Hyperbaric Medicine database; divers who presented symptoms after diving but were not referred for treatment at the hyperbaric facility were excluded. Recording of these incidents was unreliable at the aquaculture farms in the years 1988–91. We did not include minor diving incidents such as ear and sinus barotrauma or other non-diving trauma as outcome measures.

Data were sourced by the following methods:
(1) A telephone and/or written survey of all finfish aquaculture industry participants was undertaken. A structured questionnaire was administered, covering the number of divers employed, the use of log books, the number of dives from logged data, the depths of the dives, the type of diving and its frequency, limits placed upon bounce diving and specific tables used, diving equipment used, safety procedures, diver training and measures to reduce reliance on diving. Data were collected, tabulated and added to data from a previous survey in 1994.
(2) Data on diving activity from the 1988–90 period had been sourced during the preparation of the 1990 paper by Smart and McCartney. Telephone surveys or visits to industry participants had been used to obtain diver numbers. Because of direct contact made with industry members by two of the authors, the number of divers for the 1988–90 period was considered reliable. However, due to a lack of systematised recording, only estimates could be provided of the diving activity occurring in the industry, and we recognised from the outset that the initial data on the number of dives were unreliable .
(3) Field surveys were undertaken to allow direct inspection and assessment of diving practices and procedures, and of equipment.
(4) Information from the industry and also from the Tasmanian Department of Primary Industry and Fisheries was used to calculate the total number of divers in the State and the productivity of the industry.
(5) During the survey process, the authors attempted to identify other issues relevant to diver safety in the industry.

Figures were then tabulated over a ten-year period to allow comparison of the data trends over the period of the study. Because of the difficulties in obtaining accurate statistics of the total number of dives undertaken in the industry in its early years, a number of criteria were used to assess diver safety over this ten-year period.

A numerator was chosen: the number of divers with proven decompression illness requiring treatment at the Royal Hobart Hospital.

Denominators were also chosen as follows:
(1) number of divers employed in the industry;
(2) number of dives undertaken.

During the survey, it became necessary to define what was meant by a "dive" in order to maintain consistency between reports from each of the industry participants. For the purposes of this study, a dive was defined as "the period of time during which the diver was undertaking continuous diving activity with surface intervals of less than 15 minutes". Hence, where a diver entered and exited through multiple pens during the course of work, it would be counted as a single dive (multiple bounces) if the surface intervals between pens were less than 15 min.

Data were tabulated onto spreadsheets and statistical analysis was undertaken using Graphpad™ Prism software (San Diego, California, USA). Chi-squared analysis was undertaken for rates and proportions, with p values of < 0.05 being regarded as significant. Confidence intervals at the 95% level were provided, where relative risks and odds ratios were calculated.

RESULTS

Study information was obtained from all seven marine fish farm operations in Tasmania. Two of the farms had most or all of their diving operations subcontracted and, in these cases, further surveys were undertaken to ascertain the diving practices of the contractors and obtain a complete picture of the diving being undertaken in the industry. It was of particular interest that the fundamental purpose of diving in the aquaculture industry had not changed over the decade of the study. Divers still undertook the same tasks (outlined in the introduction), which were originally described in 1990 (Smart & McCartney 1990). However, there had been significant changes to the way in which diving was undertaken since the original study. The results of the present study have been grouped under the same broad headings as outlined in table 1.

Diver Training

At the commencement of the 1990s, all marine farms required their divers to be trained to a minimum level of open water recreational certification. This was further upgraded, in 1995–96, to Australian Standard 2815.2 (Restricted). Training for this was significantly more advanced than for recreational diving and equipped aquaculture industry divers with the skills necessary for diving on air to 30 m. It covered dive theory and physics, equipment maintenance, surface-supply diving, full-face masks and communications, search techniques, gas handling and testing, safety training, rescue and emergency procedures, oxygen-provider training, legislation and standards, and detailed coverage of the risks of bounce diving. In addition to training dives, a significant amount of practical work was undertaken at the marine farms; a specified duration of diving experience was included. At the time of survey (September–December 1998), the industry goal of higher level training had almost been achieved. All farms except one (three divers) were working towards AS 2815.2(R) certification for all of their divers. Five farms already had their divers trained to this standard (52 divers); one had ten divers trained and three divers with open water certification. All of the contract divers (13) were certified to a minimum of AS 2815.2(R). Hence, with 75/81 divers operating in the industry trained in accordance with AS 2815.2(R), there had been a significant move towards appropriate diver training. This compares with the 1990 study, where only two of nine divers treated for decompression illness had training appropriate to the industry (Smart & McCartney 1990).

Equipment and Equipment Maintenance

Two out of seven marine farms used "Hookah" (surface low-pressure pump) apparatus to supply air to their divers, three used high-pressure ("pods" of four cylinders) surface-supply breathing apparatus, and two farms used both (contractors using both types of apparatus). All farms had maintenance schedules for their equipment. An advantage noted for the high-pressure cylinder surface-supply "pods" was that the air purity could be independently tested, and the filling stations were subject to Australian Standard 2299 air purity

requirements. This eliminated some of the vagaries of potential malfunctions of the Hookah apparatus and their adverse effects on divers (Smart & McCartney 1990). Divers had their own personal second-stage breathing equipment (masks and regulators) at three of the marine farm operations and were responsible for its maintenance; most used safety reserve cylinders. Two of the larger operations used diver-to-surface communications, as did the contractors, and four farms used scuba as a backup to their surface-supply apparatus. All operations undertook regular maintenance of their equipment in accordance with preset schedules; cylinder pods and surface air pumps received professional maintenance and repair. Dry suits were used by many of the divers for thermal protection during colder months. Ladders were used by five farms and all contractors for divers to exit the fish pens (pl. 1). This prevented the hazardous activity of "vaulting the pen", which was described in the 1990 paper.

Safety Procedures, Diver Schedules and Profiles

At the time of survey in 1998, all of the marine farms had protocols for emergencies and carried resuscitation equipment and oxygen for use in emergencies. Individuals were appointed as safety officers and trained in first aid. Backup divers were available at four operations and were used by the contractors.

All marine farm operators and contract firms kept logs of all dives undertaken by their divers. These logs documented entry and exit times and depths for the divers, as well as documenting pre- and post-dive checks, air consumption and other dive notes. Comparisons with recognised tables also took place, in order to assign repetitive groups to the diver for residual nitrogen calculations. All farms had bounce diving limits and maximum allowable bottom times for the various depths. Table 2 summarises examples of bottom time limits provided to the authors during the survey. There were significant variations in the limits recommended by each farm. This was, however, an improvement compared with the 1988–90 period, when there was no correlation of dive times with accepted tables.

Divers were advised to undertake safety decompression stops during ascents from dives >10 m depth and to rest immediately post-diving. Recommended ascent rates at the end of each "bounce" were 5 m/min. Divers were also advised to ascend "hand over hand" in the last 3 m (aiming for 3 m/min) after their safety stop. This method has been used by the pearling industry to undertake slow ascents. Three farms included safety advice in the dive log (table 2, see example 4). With better documentation, a more comprehensive industry picture was constructed, compared with the 1990 study. The total number of dives performed annually for the period 1997-98 and the number of divers is shown in table 3. Available data allowed a calculation of the average number of ascents for each "dive". The average from all farms was 3.8 (range 3–7.3). Two farms employed contract divers to undertake most or all of their diving. None of the marine farm divers were proceeding deeper than 30 m; instead relying on contract firms to undertake this work. Contract divers undertaking deeper diving all had certification to higher level than AS 2815.2.

TABLE 2
Examples of current practice in Tasmania's aquaculture industry

	Limits on bounce diving and bottom times		
	Depth (m)	Bottom time	Maximum bounces
Example 1	10		8
	> 10		6
Example 2*	6	150	8
	12	120	8
	15	60	4
	18	40	2
	21	30	1
	30	15	1
Example 3	9–12	150	8
	12–15	75	6
	15–18	50	4
Example 4†	0–6	240	10
	7–9	180	8
	10–12	110	8
	13–15	75	4
	16–18	50	4
	19–21	35	2

* Maximum depth.

† Safety advice provided to divers on this dive log:

(1) Do the deepest dive first

(2) Always use maximum depth when finding no decompression times

(2) Add 10 min. to bottom time for every bounce

(4) Ascend slowly (hand over hand last 3 m)

(5) After diving > 10 m or bounce diving, take a safety stop at 3m for 5 min.

(6) Reduce dive times when working hard underwater.

TABLE 3
Number of divers and annual number of dives in Tasmania's aquaculture industry

Marine farm identifier	Number of divers	Number of dives
A	6	150
B	9	150
C	13	468
D	0*	0
E	3	100
F	3	100
G	34	5950
Contract pooled	13	1850
Totals	81	8768

* Contract only.

Other Practices

Creative thinking from within the industry has led to a number of other improvements in diver safety. In order to reduce bounce diving and improve productivity, larger deeper pens were introduced in the early to mid 1990s. This permitted more fish to be held in individual pens (15 000 versus 5000 previously), with reductions in maintenance and other procedures created by the economy of scale. For the divers, this meant deeper diving but less ascents and descents in their daily work, and overall less diving. In the early phase of development of the industry, a significant proportion of diving was undertaken to remove dead or diseased fish each day from the pens. The development of "mort cones" reduced the need to dive for these fish on some leases. The mort cone was a wide conical net which was lowered into the deepest part of the centre of the pen, to catch fish as they died and sank to the bottom. Perimeter nets have been traditionally used to keep seals out of the aquaculture leases. These required maintenance and were frequently in very deep water (greater than 40 m) — adding to the risk for divers undertaking maintenance. Changes in practices reduced the need for these perimeter nets in some leases. Seals were trapped using baits, then transported many kilometres away from the lease. Stronger, tensioned nets, set from the surface, and "double nets" have reduced the ability of seals to injure fish and reduced seal-bite holes in the net, which previously allowed fish to escape. The ability to set from the surface has also reduced the number of dives required. Some farms were also investigating the use of video to assist inspection processes.

Safety Outcomes Measured by Key Performance Criteria

Figure 1 demonstrates the number of cases of DCI treated at the Royal Hobart Hospital in two-year periods over the ten years, 1988 to 1998. There has been an increase in the number of cases treated, particularly over the last four years. Conversely, there has been a progressive reduction in numbers of aquaculture divers with DCI, which was statistically significant using the Chi squared test for trend, $P < 0.0001$. Table 4 shows the number of divers employed in the aquaculture industry for three of the two-year periods 1988–90, 1992–94 and 1996–98, and the number of cases of DCI treated at Royal Hobart Hospital. The table also

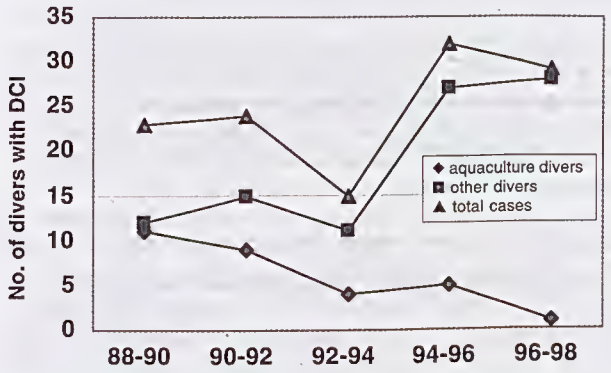


FIG. 1 — Cases of DCI treated at the Royal Hobart Hospital Hyperbaric Unit, 1 July 1988–30 June 1998. Test for trend, $\chi^2 = 17.34$, $p < 0.0001$.

documents the annual number of dives undertaken by the divers, although the 1988–90 figure is an estimate because no formal records were kept. Data were not available on diver activity for the years 1990–92 and 1994–96. Using available data, it was possible to calculate incidence of DCI per 100 divers per year and per 10 000 dives. When comparing the first two years of the survey, to the last two years, relative risk reductions for decompression illness have been significant across both parameters:

DCI per 100 divers — relative risk reduction = 16.15 (95% CI = 2.11 to 123.4)

DCI per 10 000 dives — relative risk reduction = 45.81 (95% CI = 5.91 to 354.9)

Hence divers were less likely to suffer major morbidity in the form of decompression illness in 1996–98, compared with 1988–90.

DISCUSSION

There are parallels to be drawn between the early development of the Tasmanian aquaculture industry and the South Australian tuna farming industry. A report by Kluger and co-workers in 1994 outlined similar roles for divers in the tuna farming industry and similar challenges relating to level of training, multi-ascent dives, lack of tables and high levels of diver morbidity (Kluger *et al.* 1994). Kluger's paper did not provide data on the incidence of DCI from the tuna

TABLE 4
Cases of decompression illness* from the aquaculture industry

2 year period	No. of divers	No. of dives/year	2 year cases DCI†	DCI rate per 100 divers/year	DCI rate per 10 000 dives
1988/90	50	2100	11	11	26.19
1992/94	86	5600	4	2.32	3.57
1996/98	81	8768	1	0.62	0.57
Chi squared value (2 DF)				$\chi^2 = 18.03$	$\chi^2 = 46.26$
P value				P = 0.0001	P < 0.0001

* Treated at the Royal Hobart Hospital.

† For three separate periods where diving activity was known.

industry; however, the problems faced by the South Australian industry were identical to those faced by the Tasmanian aquaculture industry at the end of the 1980s.

Information obtained in this survey of Tasmanian marine farms has demonstrated significant improvements in the industry's diving operations, when compared with the 1990 study by Smart and McCartney. The changes have addressed many problem areas, and it is pleasing to note that the process has been initiated and driven from within the industry.

Prior to the 1990s, training of divers in the aquaculture industry was ad hoc and, in some cases, non-existent. During the early 1990s, all divers were trained to a minimum level of open water certificate. This has been followed by further training by most operations in accordance with AS 2815.2(R). Compressed-air diving is unforgiving of anyone ignoring established practices and safety procedures. By equipping divers with appropriate knowledge and skills to perform their activities, the industry has invested in a safe working environment and improved productivity. With appropriate training, divers have been empowered to dive safely within established guidelines and limits, also to recognise hazardous procedures and correct them. Diving activity is now carefully recorded, depth, time and bounce limits observed, and safety measures such as decompression stops implemented. Ascent rates (3–5 m/min.) are slower than conservative recommendations of dive tables (6 m/min. in the last 6 m, summarised by Wong 1996a). Equipment is now appropriate for the tasks and maintained in accordance with established schedules. The industry has accepted that safety procedures and protocols for emergencies are an essential component of its operations. Creative thinking has reduced the amount of diving in certain activities (for example setting nets and mort diving). Use of ladders has prevented the "Polaris missile" ascent required by the diver to "vault the fish pens".

As a result of many improvements in the diving procedures of Tasmania's aquaculture industry, a significant improvement in diver safety has been demonstrated over the decade 1988–98. The incidence of decompression illness in 1998 was 0.57 per 10 000 dives (0.0057%). The reduction in risk to divers has been achieved with a background of steadily rising fish production (fig. 2). The risk of DCI in the aquaculture industry now compares favourably with Pearling Industry reports of 0.015% (Wong 1996a), and reports from the Scottish fish farm industry of 0.03% (Wilcock *et al.* 1992).

When combined with slow ascent rates, limits on bounce diving for the Tasmanian aquaculture industry may have contributed to improvements in safety. The recommended limits on the number of ascents during bounce diving for Tasmanian aquaculture divers were empirically derived, because of lack of data in this area. The average number of ascents undertaken on all farms was 3.8 (range 3–7.3). This figure was lower than expected, but probably reflects recent moves to larger, deeper pens by many of the industry participants. It is known that divers undertaking similar work in Scotland had an acceptable incidence of DCI when the number of ascents was limited to ten (Shields *et al.* 1993). Using the US Navy probabilistic decompression model, Parker and co-workers demonstrated increased risk of DCI for yo-yo diving when greater than ten descents were made, and a progressive increase in risk with deeper dives (Parker *et al.* 1994). Further research is required,

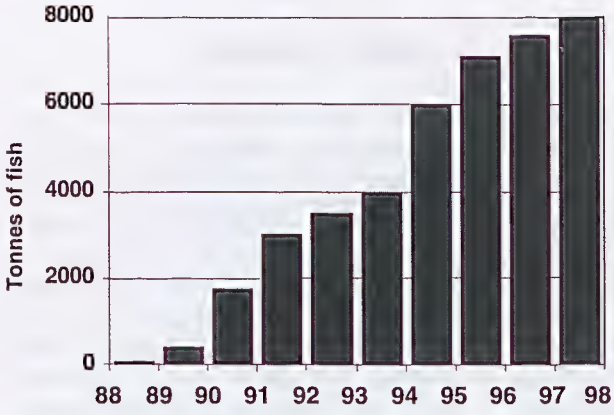


FIG. 2 — Tonnage of Atlantic salmon produced 1988–98. (Source: Tasmanian Salmonid Growers Association 1997; 1997 figures from ABARE 1998.)

undertaking carefully controlled experimental dives in sufficient numbers, before Tasmania's aquaculture industry dive schedules can be fully validated. This work should also include doppler studies using similar methodology to the pearling industry (Wong 1996b).

Bottom time and depth limits may have also contributed to the reduction in risk of DCI. The last three examples had bottom time limits which were consistent with, or more conservative than the DCIEM (1983 model) table limits (Lauckner & Nishi 1984). These tables, developed in Canada by the Defence and Civil Institute of Environmental Medicine, are more conservative than the US Navy diving tables and have been rigorously tested during working dives in cold water (Lippman 1990). Given the added (unquantifiable) risk of bounce diving, conservative limits on diver bottom time are essential. It may be possible in the future for the industry to agree on a standard set of bounce diving tables, after further more rigorous validation of existing procedures.

Dive logs also provided general advice on reducing risk of DCI. Some of the advice covered factors identified as risky practices from the 1990 study (table 1). In 1990, Smart and McCartney described aquaculture diving activity to depths in excess of 40 m. Deeper dives have been identified as an independent risk factor for DCI (Edmonds *et al.* 1992, Lippmann 1993). Since 1992, marine farm diving has been limited to depths less than 30 m (in most cases less than 21 m). Depth restrictions may also have contributed to reduced risk of decompression illness.

Improvements in diver safety have occurred with a background of increasing output from 380 tonnes of fish in 1989–90 to 8000 tonnes in 1997–98. The risk to divers of injury in 1990 was 45.8 times the risk in 1998. If the initial rates of diver injury had persisted, in 1996–98 the additional treatment costs for the industry would have been $551 000 (based on the average hyperbaric treatment cost of $3000). This figure does not include costs of lost productivity or rehabilitation expenses. These cost savings would have significant positive impact for the industry as a whole, independent of the long-term health benefits to the divers.

CONCLUSIONS

This ten-year review of Tasmania's marine finfish aquaculture diving operations has demonstrated significant improvements in diver safety, on a background of rising output from the industry. A cooperative approach, driven from within the industry, has made substantial improvements in many areas, including training, equipment and equipment maintenance, diving procedures, dive schedules and profiles, and emergency procedures. Multifactorial improvements have led to significant reductions in the number of divers treated for decompression illness from the industry. Based on the improvements in diver safety demonstrated in this paper, marine farming operations in Australia and other countries may be able to profit from the experience and achievements of Tasmania's aquaculture industry.

ACKNOWLEDGMENTS

We are grateful for the assistance provided by the following people: Mr Grant Allen (Aquatas), Ms Frances Bender (Huon Aquaculture), Mr Guy Westbrook and Mr David Conceicao (Nortas), Mr Jason Griffiths (Scuba Centre P/L), Mr Ron Morrison (Southern Ocean Trout), Mr Niels Nielsenbeck (Seafarms), Mr Mark Ransley (Seatech), Mr Jim Smith, Mr Sean Tidemann and Mr Mick Richardson, (Tassal), Mr Dave Wilkins (Petuna), Mr Tony Smithies (Tasmanian Salmonid Growers Association) and Ms Denise Garcia (Department of Primary Industry and Fisheries, Tasmania).

REFERENCES

Australian Bureau of Agricultural and Resource Economics (ABARE), 1998: *AUSTRALIAN FISHERIES STATISTICS 1998.* ISSN 1037–6879. Commonwealth of Australia, Canberra, Australia.

Douglas, J.D.M. & Milne, A.H., 1991: Decompression sickness in fish farm workers: a new occupational hazard. *Br. Med. J.* 302: 1244–1245.

Edmonds, C., Lowry, C. & Pennefather, J., 1992: Decompression sickness: clinical manifestations. *In* Edmonds, C., Lowry, C. & Pennefather, J. (Eds): *DIVING AND SUBAQUATIC MEDICINE.* 3rd edn. Butterworth Heinemann, Oxford, England: 158–178.

Kluger, M.T., Rushton-Smith, R., Williamson, J., Capps, R., Acott, C. & Webb, R., 1994: Acute and delayed presentation of decompression illness in tuna farm divers. *AUSTRALIAN AND NEW ZEALAND HYPERBARIC MEDICINE SOCIETY SECOND ANNUAL SCIENTIFIC MEETING,* Fremantle W.A., September. *Proc. Hyperbaric Tech. Nurses Assoc.*: 43.

Lauckner, G. & Nishi, R., 1984: Decompression tables and procedures for compressed air diving based on the DCIEM 1983 decompression model. *DCIEM* 84-R-74. Defence and Civil Institute of Environmental Medicine, Toronto, Canada.

Lippman, J., 1990: The DCIEM sport diving tables. *In* Lippmann J.L. (Ed.): *DEEPER INTO DIVING.* ISBN 0 9590306 3 8. J.L. Publications, Carnegie, Victoria, Australia: 279–301.

Lippmann, J., 1993: How deep is too deep? *Sources J.* 5(1): 33–36

Parker, E.C., Survanshi, S.S., Thalmann, E.D. & Weathersby, P.K., 1994: Analysis of the risk of decompression illness to yo-yo diving using the USN probabilistic decompression model. *Undersea Hyperbaric Med. 21* (Suppl.): 62.

Shields, T.G., Cattenach, S., Duff, P., Evans, S.A. & Wilcock, S.E., 1993: Decompression sickness arising from diving at fish farms. Final report. Hyperbaric research unit, Robert Gordon University, Aberdeen.

Smart, D., 1994: Diving in Tasmania's aquaculture industry. *AUSTRALIAN AND NEW ZEALAND HYPERBARIC MEDICINE SOCIETY SECOND ANNUAL SCIENTIFIC MEETING,* Fremantle W.A., September. *Proc. Hyperbaric Tech. Nurses Assoc.*: 32.

Smart, D. & McCartney, P., 1990: High risk diving. Tasmania's aquaculture industry. *SPUMS J.* 20: 159–165.

Tasmanian Salmonid Growers Association, 1997: Home Page. Tasmanian Salmon Website: www.vision.net.au/~tsga.

Wilcock, S.E., Cattanach, S., Duff, P.M. & Shields, T.G., 1992: The incidence of decompression sickness arising from diving at fish farms. *PROCEEDINGS: JOINT MEETING ON DIVING AND HYPERBARIC MEDICINE. Third Swiss Symposium, Eighteenth Annual Meeting of the European Underwater and Barometric Society.* Basel, Switzerland: 191–195.

Wong, R.M., 1996a: How safe is pearl diving? *SPUMS J. (Suppl.)* 26: 49–60

Wong, R.M., 1996b: Doppler studies on the dive schedules of the pearl divers of Broome. *SPUMS J. (Suppl.)* 26: 36–42.

(accepted 5 July 1999)

PRESERVATION ISLAND, FURNEAUX GROUP: TWO HUNDRED YEARS OF VEGETATION CHANGE

by Stephen Harris and Helen McKenny

(with two tables, one text figure, nine plates and an appendix)

HARRIS, S. & MCKENNY, H., 1999 (31:x): Preservation Island, Furneaux Group: Two hundred years of vegetation change. *Pap. Proc. R. Soc. Tasm.* 133(1): 85–101. ISSN 0080–4703. Parks and Wildlife Service, Department of Primary Industries, Water and Environment, GPO Box 44A, Hobart, Tasmania, Australia 7001.

Preservation Island was the first area south of Sydney to experience the impact of European settlement. A recent survey of the vegetation resulted in the inventory of 140 plant species, 49 of these being introduced to the island. Ten vegetation types were mapped, some of these being disturbance disclimax communities. The island has a flora typical of many of the Furneaux Outer Islands. Since 1797, *Allocasuarina verticillata*, once the likely dominant tree on the island, has been depleted almost to extinction and grassland with a high proportion of exotic species has expanded to cover more than a third of the island. Exotic species propagules have been associated with human activity on the island but also with birds and by sea drift. The high levels of natural and human-related disturbance have encouraged establishment of introduced plants. Some obligate-seeding species on the island have been reduced to either precariously low numbers (*Acacia ?genistifolia*) or extinction (*Callitris rhomboidea*) by a high fire frequency.

The biological productivity of the island was high at the time of initial human settlement because there was an extremely large muttonbird rookery, penguins, macropods and other animals. Scrub and low closed forest were more extensive. Most of the biological capital was exhausted within 30 or 40 years. The significance of the island in post-contact Australian history means that more historical remarks are recorded than would otherwise be expected for such an isolated place.

Key Words: Flora, vegetation, Furneaux Group, Bass Strait, island, human impact, biogeography, conservation, management, weeds, seabird rookery, environment history

INTRODUCTION

Preservation Island comprises 182 ha and is one of a small group of islands outside the western entrance to Armstrong Channel in the Furneaux Group. It is low and relatively flat, rising to only about 26 m above sea level. This island occupies a significant place in Australia's European history (Jetson 1996), resulting from the wreck of the *Sydney Cove* between Preservation and Rum Islands in 1797, prior to the discovery of Bass Strait. The encampment of survivors lasted for several months, and their evacuation led to the discovery of fur seals in the Straits (Collins 1802). The islands were to change dramatically from then on. The significance of the *Sydney Cove* in Australian history is discussed by Cumpston (1973), Fowler (1980) and Nash (1996).

Preservation Island has been more or less continuously used as a grazing island for nearly 200 years, although it has only been intermittently occupied by people over this time. Other than about 60 head of cattle being grazed on the island at present, there are no introduced grazing animals, and the original macropods on the island have become extinct. A sealer named Munro lived on the island for a number of years, and Maclaine of Clarke Island leased the island for grazing for several decades. The island has had many prominent visitors. For example, Captain Baudin and some of his officers and crew spent some time on the island and have left written records of their impressions. Commander J.L. Stokes in the HMS *Beagle* also spent some time on the island.

The island comprises mainly Crown land. There is a private freehold block of 20 ha, and the present owners, the Preservation Island Unit Trust, hold a lease on the Crown land. The southeastern portion of the island (10 ha) is part of the *Sydney Cove* Historic Site, which was proclaimed under the *National Parks and Wildlife Act* 1970 by virtue of Statutory Rule No. 55 of 1977. The funding available for rehabilitation of the natural environment, through the Commonwealth's Natural Heritage Trust programme, has inspired a new focus on the outer islands of the Furneaux Group, which are known to have high nature conservation values as well as a long history of degradation by human activity. Preservation Island is an ideal case study, where the nature and magnitude of change can be assessed. The island exhibits the results of more than two hundred years of European impact on its vegetation. It is a confined and clearly identifiable area to which we can attribute a long span of recorded observations.

The Outer Furneaux Islands are of biogeographical interest (e.g. Hope 1972, Hope *et al.* 1973), but human impacts on their floras vary throughout the Group. The specific aims of this study were to document the vegetation and flora of the island, and its conservation status and biogeographic relationships; also to examine the impacts of human use of the island on the vegetation, and to make recommendations for improving the condition of the native vegetation.

METHODS

This study is based on three visits to the island. The first two, in 1979 and 1987 (by SH), were for brief botanical reconnaissance; the third was an expedition on 24–26 March 1999, when more detailed work was carried out by both authors.

(1) The photocommunities were first directly mapped onto a black and white aerial photograph, dated 27 November 1993, which had been enlarged to 1:10 000 scale.

Photocommunities were areas of uniform texture and tone.
(2) Several informal transects were chosen to enable all the perceived vegetation types to be sampled.
(3) The full range of vegetation was sampled by 29 100 m^2 plots located using the "subjective without preconceived bias approach" of Mueller-Dombois & Ellenberg (1974) in the range of vegetation types. At each plot, a list of all vascular plant species was made. Percentage cover of the dominant species in each stratum was noted, as well as vegetation structure following the style of Specht (1970). Topographic, substrate and locality information was also collected. Data sheets have been bound and lodged in the library of the Department of Primary Industries, Water and Environment, Hobart.
(4) Other observations along the transects were used to supplement the plot information and assist in interpreting the processes influencing the vegetation.
(5) The boundaries of photocommunities were checked and adjusted after ground truthing and used to compile the vegetation map. An aerial photograph dated 22 February 1986 was used to assess visible changes in vegetation during the period 1986–93.
(6) Floristic communities were identified by hand-sorting of the species lists and were compared with those listed in Kirkpatrick *et al.* (1995) to assess reservation status.
(7) Plant nomenclature follows Buchanan (1999). Conservation and reservation status of species was assessed against published lists and the schedules to the Tasmanian *Threatened Species Protection Act* 1995.
(8) A search of the historical literature and sources was made to collect information that would contribute to an understanding of the past vegetation pattern.
(9) One of us (SH) has visited all vegetated islands in the Furneaux Group, enabling us to make comparisons between Preservation Island and others in the Group.

PHYSICAL DESCRIPTION: GEOLOGY, SOILS AND CLIMATE

The island is formed of medium to coarse-grained Devonian granite with some remnant calcarenite exposed on the sheltered parts of the shoreline. Windblown sand occurs on the southeastern side of the island.

The nearest climate station relevant to Preservation Island is at Swan Island, about 30 km to the southeast. Swan Island records an annual average rainfall of about 616 mm, with the highest monthly falls during winter. Average summer minimum and maximum temperatures are 14.6°C and 20°C respectively; the average winter minimum and maximum are 8.2°C and 12.8°C respectively. Local records on Preservation have been used to suggest an annual rainfall average of only 150 mm (Jetson 1996), and an annual average of 468 mm, which is predicted by BIOCLIM modelling, still puts the rainfall in the driest part of the Furneaux Islands. The climate is classed as Mediterranean type. Winds are persistent, predominantly westerly and often very strong.

HISTORICAL ACCOUNTS OF THE VEGETATION AND HABITAT

An analysis of historical observations on the vegetation of Preservation Island and of events that might have shaped the vegetation is important.

The first European contact with the island was on 8 February 1797, when the survivors of the *Sydney Cove* shipwreck landed safely on the island and pitched their makeshift tents, according to Cumpston (1973) "close to a tufted grassy patch full of burrows". The first stock was landed on the island, namely a mare, a cow, some fowls and some pigeons. These would have had no significant impact on the flora of the island. Cumpston (1973) also claimed that "fires to cook the rice were only kept alight with difficulty". This is not because of any apparent shortage of firewood but because of the rain and strong winds. After news of the wreck reached Sydney, the authorities feared the islands could attract deserting convicts as "it was already well known that the island [Preservation] abounded in birds and kangaroos" (Cumpston 1973).

It is difficult to reconstruct the vegetation at the time of the *Sydney Cove* wreck. The impact of the survivors during their several months stay may have been considerable. Depletion of macropods and deliberate and accidental fires would have been probable early impacts.

Two stone lookout structures, likely relics of the *Sydney Cove* survivors (M. Nash, pers. comm.) and sited so as to give unimpeded 360° views of surrounding waters (e.g. pl. 1), occur on the island. It is assumed that the views from these structures were not impeded by tall vegetation. On the higher ridge of the island, therefore, the vegetation may not have exceeded 4 or 5 m height at most. Certain vantage points were visible from the sea because Flinders (1801) wrote:

> When coming from the westward to Preservation Island, the island is hid under the higher land of Clarke's Island. Lumps of white rock first appear upon it, and upon Night Island.

PLATE 1

The figure is standing at the inward margin of a patch of Euphorbia paralias *which has colonised a rear-dune blow out on the west coast. The bushes in the background amidst the* Poa poiformis *grassland are boxthorns (*Lycium ferocissimum*).* Austrostipa stipoides *occurs in the left foreground. One of the old constructed lookouts on the island is visible on the horizon in the left distance.*

Flinders would have been referring to guano-stained tors and rocks.

Cumpston (1973) reported that when he left Preservation Island,

> Captain Hamilton [from the *Sydney Cove*] left in the house two hens sitting upon eggs, some breeding pigeons and a bag of rice. He reported that good fresh water was collected in certain seasons in small pools on swampy land near the east end of Preservation Island. The water that drained in a small rill was at first used by the crew, but was thought to have a deleterious quality from the deaths that occurred amongst the crew after drinking it.

Two observations from Nicholas Baudin (Cornell 1974) indicate some more substantial vegetation on Preservation Island. On 10 March 1802, Baudin noted in his journal:

> The skipper of this schooner also gave me some information concerning good anchorages in the Furneaux Group and especially off the island that the English have named Preservation Isle, where, according to them, wood and water are easily obtainable.

Baudin (Cornell 1974) made a further reference to the vegetation of the islands on 17 March:

> The Furneaux Islands at the entrance to the strait appear bare of trees and even of greenery (or rather, one sees very little of it), but further in, they are well wooded and pleasant."

From the corvette *Naturaliste*, seaman Brevedent reported in his journal (cited in Plomley 1983) a landing on Preservation Island on 13 March 1802. He accompanied geographer Faure, botanist Leschenault, and mineralogist Bailley. Plomley describes how

> ... they found the wreckage of a ship of 200–300 tons, and huts made of branches tied together with cordage. On the island they found eggs in great quantity, as well as penguins, crows and kangaroos.

Baudin claimed (Cornell 1974) that

> On Preservation Island particularly, where I stayed for three days, the birds often contended with us by pecking for a place around the fires we had kindled to dry our clothes...

About 1810, the island was settled by a sealer named Munro, who is mentioned in some usefully explicit remarks about the island given by Campbell in his memoir of 1828:

> Preservation Island is low and sandy. The length is about 3 miles and the average width is about 1/2 of a mile. Munro ... has his residence on the east end fronting Cape Barren Island.
>
> ... The original name of the island was "Mutton Bird Island" from its being almost covered with these birds, who build their nests in the ground so as almost to cover the entire surface of the land. Wood grows on the west end of this island of the kinds common to Van Diemen's Land, but principally she-oak. Excepting the western extremity, the other parts of the island are almost free from trees or brush wood.
>
> ... Water is procured from a small lake or lagoon, on the east end, which is generally covered with ducks and teal.

The meaning of the term "brushwood" is implicit in Flinders' (1801) journal when he wrote of the Furneaux Islands:

> As far as my particular knowledge of the islands extends, their surface is bare rock, in part; or sand which is covered with brush wood; or swamps, in which small trees grow. The brush is very often impenetrable; sometimes growing to a considerable height, and sometimes creeping along the ground; the tall brush-wood is found in the inner and eastern parts of the islands, and the scrub on the western outskirts: a proof of the strength and prevalence of westerly winds.

There is no direct evidence for sealing being carried out on Preservation Island, but the island became a "crossroads" for traffic associated with sealing and other activities in the early history of Bass Strait (Kostoglou 1996). By 1830, the tree cover had been depleted to the extent that G.A. Robinson noted in his diary for 9 November 1830 (Plomley 1966):

> There is no wood on Preservation Island and M has to fetch it all from Cape Barren.

In the 1830s and 1840s, there were a number of recorded visits by, amongst others, George Augustus Robinson, Commander Stokes and officers of the *Beagle*, and the Quaker missionaries, Backhouse and Walker. Collectively, their comments provide interesting clues as to the nature of the evolving vegetation. On the 8 October 1832, Backhouse and Walker (Plomley 1987: 221–222) reported that they:

> ... visited the establishment of James Munro. ...His hut is built of branches, and the intervening spaces filled up with grass and rushes. He has a piece of ground paled round as a garden, in which he grows vegetables of various kinds, and a second piece on which he grows corn, etc.
>
> One of the men named John Hughes walked with us to the western part of the island, which is grassy, with here and there suffructicose plants, upon a light soil. ...The burrows of these birds are so close to one another that one is in constant danger of breaking into them at every step over many acres of ground.
>
> We saw one of those formidable animals (snake) more than five feet long, and gave it a blow which made it rear its head with threatening aspect, but it took refuge in a neighbouring hole, and as the only switch we could raise was a feeble one of *Correa alba*, we did not think it expedient to repeat the blow. ... There are no trees on the island, nor is there any tall scrub except a few tea-trees about J. Munro's house.
>
> A species of *Lavatera* (*L. plebia*) resembling *L. arborea* was in flower on the slopes down to the shore, on which was also plenty of *Polygonum adpressum* (the Macquarie Harbour grape) and abundance of nettles of very powerful sting.
>
> J. Munro has a number of pigs and goats and fowls upon Preservation Island ...

The observation that goats were present on the island is important for the impact that they may have had on the vegetation. Their impact, particularly on island floras, has been well documented (Parkes *et al.* 1996). Moreover, Begg & Begg (1979) gave an unsourced quote (possibly Boultbee's Journal) that James Munro had "upwards of 800 goats" on the island.

In a general observation of the islands passed on a voyage to Big Green Island by way of the Chappell Islands, Backhouse and Walker stated that

> Many of the islands are low and grassy ... The herbage on Green Island is very similar to that of Preservation, but more luxuriant.

and further that:

> Preservation Island is low and covered in grass, barilla, nettles etc. A large portion of it is burrowed so thickly by muttonbirds that it is difficult, in many places, without breaking at almost every step into their holes.

Of domestic plant introductions, they observed that Munro "also grows wheat, potatoes and other vegetables".

Backhouse was an excellent botanical and natural history observer. The excerpts above are of interest because particular species are mentioned and some important information about the vegetation is included. There is an apparent contradiction between the Backhouse and Walker report and the report by Campbell (1828), who said the woody vegetation was on the westerly end on the island, while other parts were free from trees and brushwood. One possibility is that Campbell mistakenly reversed west and east.

In 1842, when Commander Stokes and officers of the *Beagle* stepped ashore on the island, he reported (Stokes 1846) that

> I found Preservation Island inhabited by an older sealer of the name of James Munro, generally known as the King of the Eastern Straitsmen. Another man and three or four native women completed the settlement, if such a term may be applied. They lived in a few rude huts on a bleak flat, with scarce a tree near, but sheltered from the west by some low granite hills; a number of dogs, goats and fowls constituted their livestock. In this desolate place Munro has been for upwards of twenty-three years.

VEGETATION COMMUNITIES

Atriplex cinerea Shrubland

The distinctive vegetation on the muttonbird rookeries comprises 2 ha or 1% of the island (fig. 1). Historical sources indicate that muttonbird burrows once covered most of the island but after 200 years of stock access to all the island, harvesting and burrow destruction, the area has considerably diminished. It is clear that *Atriplex cinerea* was a dominant plant on the island at least in the 1830s and 1840s.

The vegetation on the rookeries varies slightly but is distinguished either by succulent creepers, such as *Carpobrotus rossii* and *Tetragonia implexicoma*, the succulent herb *Senecio lautus* and the scrambling shrub *Rhagodia candolleana* or by *Atriplex cinerea* (pl. 2). On the southern end of the island, extensive areas of the silver-coloured shrub *Atriplex cinerea* indicate calcareous sands with numerous burrows. Burrow density, however, does not appear to be as high as in rookeries on ungrazed islands. This may explain the low diversity of species. The disturbance species which occur in other rookeries, i.e. *Lepidium foliosum, Actites megalocarpa, Lavatera plebeia,* are rare or absent. *Poa poiformis* and *Lycium ferocissimum* are rare in the rookeries. The tallest vegetation layer of *Atriplex cinerea* has a patchy cover with an average plant height of approximately 0.3 m; the ground cover species have around 95% cover.

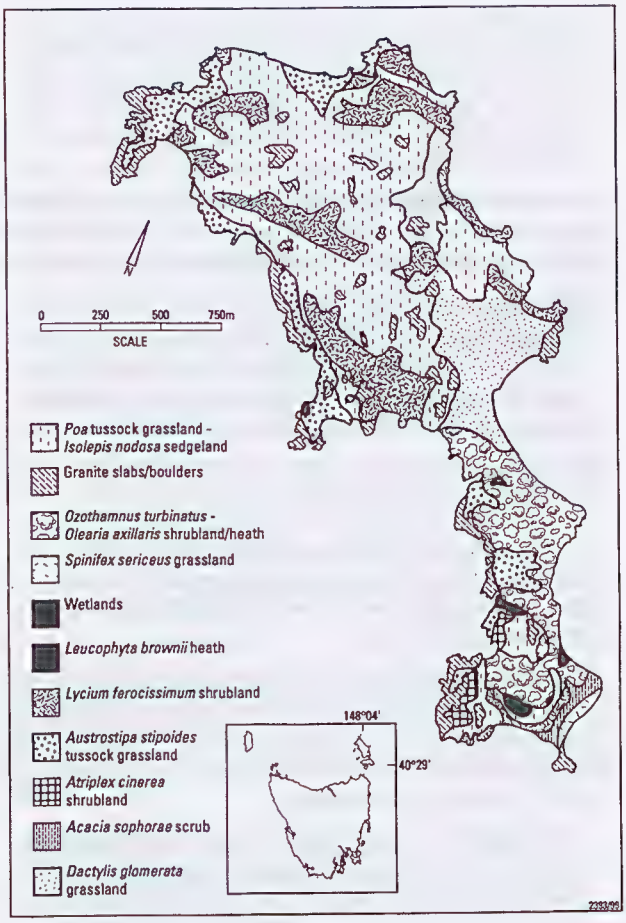


FIG. 1 — Distribution of vegetation types on Preservation Island.

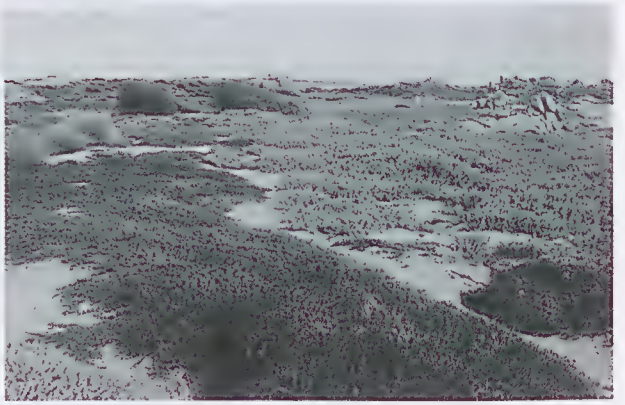


PLATE 2

Atriplex cinerea *shrubland on the southeastern coast, bounded by a succulent herbfield of* Carpobrotus rossii *in the foreground. Note the wind pruned* Lycium ferocissimum *in the middle distance.*

Ozothamnus turbinatus–Olearia axillaris Heathland

This vegetation type is predominant on the deep sandy soils at the southern end of the island and occupies 22 ha or 12% of the area. There is a range of facies in this type. For example, at plot 9 there was the disturbed remnant of a facies, which may have formed a closed heath of *Ozothamnus* and *Olearia axillaris* but appears to have been destroyed by wind. The inclination of the trunks indicates a strong influence from prevailing winds. Once the closed heath is breached by the wind, the physical damage is great. Other species which occur in this community include *Threlkeldia diffusa, Tetragonia implexicoma, Carpobrotus rossii, Apium prostratum* and *Isolepis nodosa.*

The heathland at plot 9 had developed by slow height increment, the rate of this being governed by the mutual protection afforded by the density of the shrubs. As the vegetation is dense, and the foliage which is presented to the wind is planed to an even surface, the salt-laden winds tend to prune any new growth emerging above this surface. Gain in height is only made when sufficient spells of relatively calm weather coincide with a growing period. The vegetation density prevents wind from penetrating the shrub layer.

The same principle explains the "wind row" effect, a pattern which is visible as striations on the aerial photograph. The shrubbery is formed into linear rows aligned with the prevailing wind. Whether there is a shrub row or a wind corridor, or shrub rows of different heights, depends on the features intercepted by the wind at the seaward boundary of the community. The position of a salt-tolerant shrub, a boulder or any other protruding feature will be enough to assist growth of vegetation to the leeward.

Southeast of the hut and close to the track is a tall heathland or low open shrubland, dominated by *Lycium ferocissimum, Leucopogon parviflorus, Olearia axillaris* and *Ozothamnus turbinatus.* Diversity is higher, perhaps because the vegetation borders a disturbed open area close to a weed invasion source by the track. Other shrubs or potential shrubs at this site were *Correa alba* and *Pimelea serpyllifolia.* Grasses and herbs included *Catapodium rigidum, Melilotus albus, Trifolium* sp., *Bromus diandrus, Epilobium billardierianum, Austrofestuca littoralis, Muehlenbeckia adpressa, Hypochoeris radicata, Lagurus ovatus* and *Isolepis nodosa.* The succulents *Senecio lautus, Carpobrotus rossii, Rhagodia candolleana* and *Tetragonia implexicoma* also occur. It is expected that some of these species will be transitory and will not persist once the shrubs assume dominance.

Further upslope on a dune crest, a relatively intact shrubland occurs, which was dominated by *Pimelea serpyllifolia, Olearia axillaris* and *Leucopogon parviflorus.* Fewer exotics occur than in the more open disturbed site. *Chrysocephalum baxteri* is common here and climbs amongst the shrubbery. *Myoporum insulare* occurs as a low shrub and could potentially dominate as part of a low closed forest with other potential tree species. The other two tree species noted in this community were *Allocasuarina verticillata,* which was represented by one 4 m emergent individual (pl. 3), and *Bursaria spinosa,* represented by some low shrubs, which bore empty seed capsules at the time of our March visit.

This community has a dense cover, which reaches 90–100% in some patches, with few herbs and grasses growing in the shaded understorey. Where the shrub layer canopy is more broken, the ground layer increases its cover up to 70–80%. The community probably retains most of the elements it had prior to European contact, although the rarity of some species which could be expected to dominate and the total absence of others indicate a slow extinction process. *Callitris rhomboidea,* for example, should probably have occurred here. The structure of the community is likely to have changed considerably since European contact, for instance, cattle tracks are evident throughout.

PLATE 3
Ozothamnus turbinatus–Olearia axillaris *shrubland gives way in the foreground to a patch of taller closed shrubland with an emergent she-oak (*Allocasuarina verticillata*) arrowed — the only survivor noted on the island. In 1979 there were three specimens on the island.*

Native Sand Dune Grassland

Very small areas dominated by *Spinifex sericeus* and *Austrofestuca littoralis* occur around the island, occupying about 1 ha or <1% of the island area. The best example is at the southern end of the island, where sand accretion appears to have been taking place. A zone of acid sand, about 20 m wide or more, is colonised mainly by *Spinifex* and *Austrofestuca.* The community is very species-poor and only *Actites megalocarpa, Epilobium billardierianum* and isolated low shrubs of *Olearia axillaris, Pimelea serpyllifolia* and *Leucopogon parviflorus* occur. The total vegetation cover is around 90%, with much of the ground cover being contributed by moss on the older part of the beach.

To landward of this grassland is a dense closed shrubland dominated by *Acacia sophorae* and *Leucopogon parviflorus.* The *Acacia* appears to be slowly spreading out onto the grassland, but the shrubby pioneers appear to be *Ozothamnus turbinatus* and *Olearia axillaris.* This zone, with its invading shrubs, is also characterised by hydrophilus mosses on the older sand, whereas in a swathe parallel to and closer to the shore, there is no moss on the sand surface. *Euphorbia paralias* occurs at the northern end of this beach and numerous seedlings are evident.

Bare Granite Slab and Boulder Communities

The communities occurring on granite slabs and boulders are distinctive and represent plant assemblages responding to very particular environmental conditions. Hunter (1998) has advocated the separate mapping of such habitats in

vegetation surveys. They were distinguished in this survey and occupy 13 ha or 7% of the island.

It seems there are several broad types of granite slab and boulder habitats. Groups of rocks or boulders with high inaccessible crevices provide fire and disturbance-protected niches for some plants. On many of the outer islands of the Furneaux Group, species such as *Cyathodes juniperina, Olearia phlogopappa* and *Alyxia buxifolia* occur in such areas. There seems to be a depauperate boulder refugia diversity on this island, perhaps attributable to the long history of human impacts through grazing animals and fires. Goats were known to have been on the island for a long period, at least during the 19th century, and most of this habitat would have been accessible to them. Species observed in the refugial sites amongst boulders are *Asplenium obtusatum, Agrostis aemula* var. *aemula, Myoporum insulare* and *Lycium ferocissimum.*

The other two main habitats associated with granite slabs and boulders are runnels and crevices with skeletal soil, which are highly susceptible to drought (pl. 4), and skirting communities, where a distinctive community occurs on the periphery of granite slabs. At the periphery, there is a buildup of gravelly detritus, and moisture is available in larger but infrequent amounts through runoff. There is a wide range of microhabitats, but unreliability of moisture is the major limiting factor. The runnel communities are often characterised by shallow soils in rills of varying sizes. In times of rain, these would soak up considerable moisture. The drying out would occur fairly slowly, perhaps impeded by the surficial lag of quartz and feldspar detritus on the surface. *Crassula sieberana* subsp. *tetramera* is the most ubiquitous species. Other plants commonly occurring include *Plantago coronopus, Centrolepis strigosa, Hypochoeris radicata, Bulbine semibarbata* and *Dichelacne crinita. Brachyscome diversifolia* is also common. *Acacia ?genistifolia,* which is uncommon in the surrounding shrubland, is found in crevices. This accords with Hunter's observation (1998) that obligate seeders, which may be disadvantaged by a high fire frequency, can survive in a fire-protected crevice. The species in this community have patchy cover, overall less than 25%, and generally are low growing, reaching a maximum height of 0.1–0.15 m.

The skirting communities vary, depending on particular site circumstances, but commonly there is a strong, simple zonal influence, where the marginal community is dominated by *Crassula sieberana* subsp. *tetramera* or *Bulbine semibarbata.* This specialised niche is defined by the infrequent and unreliable appearance of surface runoff from the granite slab. Otherwise, the habitat is very dry, because the soil is very shallow, no more than 10–20 mm deep.

Acacia sophorae Closed Scrub

This vegetation type occurs on stable sand dunes at the rear of the easternmost beach (pl. 5), and comprises only about 1.5 ha or <1% of the island. The vegetation is dominated by *Acacia sophorae* and *Leucopogon parviflorus,* which have more than 90% canopy cover and stand at 3 m. The understorey is sparse in terms of species numbers, but patches occur where *Rhagodia candolleana* climb through the scrub. *Pimelea serpyllifolia, Lepidosperma gladiatum* and *Poa poiformis* form variously scattered or patchy occurrences on the ground. The litter layer is almost 100% but is no more than 10 mm over sand, indicating that this vegetation is not very old. The largest *Acacia sophorae* had a dbh of 0.2 m.

Wetlands, Damp Herbfields, Soaks and Moist Halophytic Grasslands and Herbfields

A range of specialised habitats is reported and discussed here. Altogether, such habitats probably comprise about 1 ha or <1% of the island. The variation in these types is discussed under subcategories. Some subcategories comprise elements of others.

Wetlands

There are no lagoons or swamps which permanently hold water on the island. The only true swamp is on the south-eastern part of the island. Roughly rounded in outline, the site is surrounded by shrubland on stable sand dunes. The

PLATE 4
Granite slabs have distinctive assemblages of plants in crevices and depressions.

PLATE 5
The southeastern shore of the island from the air. The beach is accreting, apparently through longshore drift of sand from the left. The dark patch is the Acacia sophorae *closed scrub. An intermittent lagoon is visible as a darker patch in the extreme lower right hand corner of the photograph.*

wetland is zoned and comprises an outer zone dominated by *Juncus kraussii* with abundant *Apium prostratum* climbing through these. A wide zone occupying most of the wetland is a halophytic herbfield comprising a dense cover of *Sarcocornia quinqueflora* and *Suaeda australis.* The central depression had no free surface water but was mainly bare ground with *Cotula coronopifolia* and *Atriplex prostrata.* The ground cover is nearly 100% at this site, with the taller species in general reaching not more than 0.5 m in height.

Soaks

These occur around the coast, where groundwater appears out of the interface between granite bedrock and overlying sands or calcarenite (pl. 6). The sand is usually a dark brown indurated layer above the bedrock. The soaks vary in their flow rate, species composition, size and condition, according to whether there is natural or fenced protection from stock, amount of shading, and degree of exposure.

At one fenced soak on the southeastern shore, microtopography varied greatly within a 1 m range, with *Poa poiformis* occurring with *Trifolium fragiferum, Leucopogon parviflorus* and *Stipa stipoides* on the higher parts. No aquatic species were observed where the water had been artificially ponded by a small concrete dam, but a dense halophytic herbfield dominated by *Sarcocornia quinqueflora* occurred alongside patches of *Isolepis cernua.* Other species present included *Apium prostratum, Disphyma crassifolium, Distichlis distichophylla, Vellereophyton dealbatum, Hordeum murinum* ssp. *glaucum, Plantago coronopus, Mimulus repens* and *Lobelia alata.* Below this dam, outside the fenced area, there was abundant *Chenopodium pumilio. Isolepis cernua, Disphyma crassifolium, Carpobrotus rossii, Apium prostratum* and *Cotula coronopifolia* were present. Vegetation cover is 100% around the dam in the fenced area and 20% outside.

Damp herbfields and halophytic grasslands

These occur on flat depressions close to the shore, often where onshore winds can carry and deposit salt spray. *Distichlis distichophylla* is the common dominant, sometimes forming dense monospecific carpets. In some areas, *Austrostipa stipoides* occurs on the more exposed areas. Other common species include *Sarcocornia quinqueflora, Plantago coronopus, Isolepis nodosa, Melilotus albus, Dichondra repens, Lobelia alata, Tetragonia implexicoma, Senecio lautus, Cotula coronopifolia, Disphyma crassifolium* and *Apium prostratum.* At plot 10, these were supplemented by the exotics *Holcus lanatus, Trifolium* sp., *Hypochoeris radicata* and *Anagallis arvensis.* The height of this vegetation is less than 0.3 m and ground cover is 100%.

Coastal Fringe Vegetation

Preservation Island is low, relatively flat and very exposed, therefore no area escapes maritime influence. Distinct detectable coastal vegetation zones are hardly discernible on the aerial photograph as a mapping community apart from the distinctive *Spinifex* grassland and the *Acacia sophorae* scrub on the southern end of the island. Elsewhere, the impact of stock has been extended right to the shore. The circumcontinuity in any zoning that might once have occurred has been disrupted, and now small pockets of predominantly native littoral species occur in areas protected from stock and humans. The exotics *Cakile edentula, C. maritima* and *Euphorbia paralias* are the dominant strandline species, and these are especially common on the northern and western shores of the island.

Poa poiformis Tussock Grassland–*Isolepis nodosa* Sedgeland

The *Poa poiformis* tussock grassland and *Isolepis nodosa* sedgeland communities are regarded as close facies variants and share a similar suite of species. The *Isolepis nodosa* sedgeland is detectable on black and white aerial photographs as darker, uniformly textured areas, and the circular clonal groups can sometimes be seen. Collectively they are the most widespread vegetation communities, covering 71 ha, or approximately 39% of the island (pl. 7). Many species are common to both vegetation types, including *Bromus, Plantago coronopus, Melilotus albus, Trifolium* sp., *Cirsium vulgare,* and *Acetosella vulgaris.* The maximum height of this vegetation is 1 m where *Isolepis* occurs but is more commonly

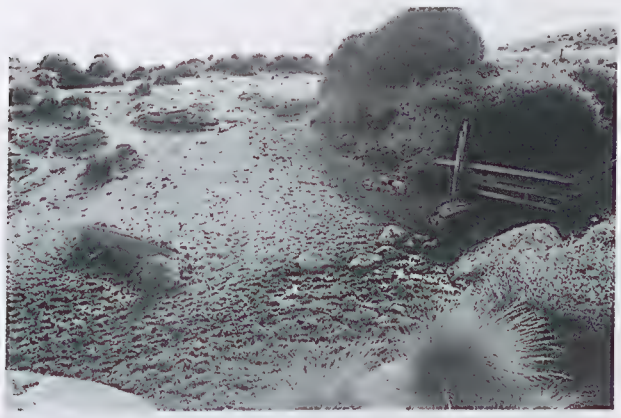


PLATE 6
A fenced off spring on the south coast of the island. Erosion and damage to the damp herbfield has occurred.

PLATE 7
Looking east across the island. Poa poiformis *grassland is the predominant vegetation visible. Rum Island is in the distant right.*

around 0.3 m. The cover averages about 80%. Both *Poa poiformis* and *Isolepis nodosa* are common in most vegetation types across the island.

Austrostipa stipoides Tussock Grassland

Austrostipa stipoides tussock grassland is most extensively developed at the western extremity of the island, where there is full exposure to onshore westerly winds. Smaller patches occur discontinuously around the more exposed sections of coast, particularly the south coast. Altogether, this vegetation type occupies 18 ha or 10% of the island. At the western end of the island, the tussocks reach around 1 m in height and are very dense, but some intertussock spaces occur. There is 100% ground cover, the species including *Gamochaeta purpurea, Melilotus albus, Dichondra repens, Trifolium* sp., *Plantago coronopus, Tetragonia implexicoma, Rhagodia candolleana, Actites megalocarpa, Dichelachne crinita, Brachyscome diversifolia* and *Isolepis nodosa.* These species rarely share the *Austrostipa* canopy at 0.6 m but are found between the tussocks, contributing to a layer at about 0.1–0.2 m in height. Where the *Austrostipa* meets the spray zone, the transition is directly to *Disphyma crassifolium* and *Frankenia pauciflora* in some highly exposed areas.

Lycium ferocissimum Shrubland

This mapping community occupies 31 ha or 17% of the island (pl. 8). The boxthorn generally reaches between 1 and 3 m in height and remains prevalent in *Poa poiformis* tussock grassland and *Isolepis nodosa* sedgeland. Shrubs can coalesce to form patches with 100% cover. There are no co-occurring species which are always associated with *Lycium*; however, its thorny nature allows plants which would otherwise be heavily grazed to thrive. Examples are *Dichondra repens, Chenopodium pumilio* and *Rhagodia candolleana. Lycium ferocissimum* individuals occur throughout the island in all communities except the *Spinifex sericeus* grassland and *Acacia sophorae* scrub.

According to Reg Munro (pers. comm., 7 June 1979), there was no boxthorn on the western part of the island in the early 1950s, but it spread rapidly throughout the islands, apparently after starlings became established. Extensive areas of boxthorn, evident on the 1986 aerial photograph, have been removed by the present lessees.

Dactylis glomerata Exotic Grassland

This community occurs on Munro's Flat, where the airstrip and the hut are located (pl. 9). The area is maintained free of tussock for use by aircraft. The total area occupied by the community is 23 ha or 13% of the island. The grassland is closely grazed and kept slashed. Many of the species occurring in this community are common to *Poa poiformis* tussock grassland and *Isolepis nodosa* sedgeland. *Chenopodium murale* is an introduced species favoured by trampled stockyards, but also prone to grazing. It occurs in the fenced compound around the hut and was observed in a fenced area of this community southwest of the hut. This grassland is closely grazed to less than 0.1 m average height and has a cover of more than 90%.

Leucophyta brownii Heath

This community occupies less than 1 ha or <1% of the island. The *Leucophyta* may form open or closed heaths. The dominant is tolerant of salt-laden onshore winds and seems also to thrive in areas of active erosion or unstable substrates. One small patch of *Leucophyta* dominated an old sand blowout and was associated with *Zygophyllum billardierei* and *Threlkeldia diffusa.* It also dominates in some small areas on the southern shore. The community has a total cover of only 50%, and is uneven in height up to about 0.4 m.

PLATE 8

On the southeast coast, a zone of Atriplex cinerea *shrubs gives way to* Lycium ferocissimum *shrubland. The beach has a heavy clump of sea grass, originating from the* Posidonia australis *sea grass beds in the shallows offshore.*

PLATE 9

The Dactylis glomerata *dominated exotic grassland looking west towards the hut. The darker patches are* Isolepis nodosa.

THE FLORA

The vascular flora observed on the island amounted to 140 species from 119 genera in 49 families. Just over one-third (49) are introduced species, a similar ratio as for the whole Tasmanian flora. The *Poaceae* (n=23) and the *Asteraceae* (n=22) are the best represented families. The next most well-represented families are *Fabaceae* (n=9) and the *Chenopodiaceae* (n=8). There is a high proportion of species which are also characteristic of dry coastal floras in South Australia. For example, in an extensive coastal botanical survey around Spencer Gulf, Kangaroo Island and southeastern South Australia (Oppermann 1996, 1997), species lists were made at 384 quadrats. Sixteen (including 2 exotics) of the 20 most frequently occurring plant species in that survey are also prominent on Preservation Island. This similarity underscores the strong affinity of these islands with the drier South Australian coast. Another similarity is the presence of calcarenite and highly calcareous sands in Bass Strait and on the South Australian coast. Sixty-six percent of the Preservation Island flora overlaps with the total species list from Oppermann (1997) together with species recorded from South Australia's offshore islands by Robinson *et al.* (1996).

Exotic Species

The high levels of natural and human-related disturbance have encouraged the establishment of exotic species. Transport of propagules has been through birds, by sea, from stock and from materials and other goods brought in by people.

Some of the introduced species are widespread cosmopolitan plants, which would have been present from soon after European exploration. These include *Plantago coronopus, Cakile edentula, C. maritima* and *Catapodium rigidum.* The exotic species comprise plants which would have been accidentally or deliberately introduced in the course of introducing and providing pasture for livestock. These include *Bromus, Holcus lanatus* and *Dactylis glomerata.* Continuing disturbance and nutrient concentration would contribute to the persistence of herbaceous weeds, especially in the *Poa poiformis* tussock grassland – *Isolepis nodosa* sedgeland. Other exotics are considered aggressive colonisers which pose a threat to the environment. These are *Lycium ferocissimum, Cirsium vulgare* and *Euphorbia paralias.*

The spread of exotic species has been occurring since the earliest days of European ships in southern waters. For example, it has been claimed (Heyligers 1987) that species like *Cakile maritima* and *Euphorbia paralias* may have spread rapidly around the coast, once introduced into Australian waters in ships ballast. There are many small weeds which are widespread around the southern latitude coasts. For example, on the Crozet Islands in the Southern Ocean, at latitude 46.5°, at least 10% of the introduced species and congeners representing a very high percentage of the remaining 90% of Crozet weeds (Carcaillet 1993), also occur on Preservation Island.

Many of the exotic species have been introduced in association with agriculture. Reports of gardens on the island early last century growing wheat, corn and potatoes have left no physical legacy. *Marrubium vulgare* is a persistent farmyard and 19th-century garden plant, which tends to stay close to its point of origin and seems to be a good indicator of historic sites such as long-gone farm houses and huts. *Lycium ferocissimum* was probably first introduced to the islands of Bass Strait for windbreak plantings around huts and houses. It has spread throughout all the islands, aided by birds (e.g. starlings) eating the fruit and expelling the seeds over a widespread area. Some islands have become completely infested by boxthorn and it would rapidly overtake Preservation Island without continued efforts to control the population.

Euphorbia paralias is beginning to take a hold on the island (pl. 1). Its distribution and spread in Tasmania have been discussed by Harris & Davis (1995), Harris & Kirkpatrick (1996) and Harris & Balmer (1997). Heyligers (1987) showed how it has spread from Western Australia. Willis (1953) stated that:

> *Euphorbia paralias* is an interesting new record of a littoral, alien species which I found only at one place, viz. the extreme eastern part of the beach on Goose Island Bay (Middle Island) where it was well established amongst driftwood and clumps of *Scirpus nodosus.* The only other Australian location of this European Sea Spurge would seem to be on the west coast of Yorke Peninsula, South Australia, opposite Wardang Island – perhaps the two widely separated occurrences are linked by the visit of some ship?

It is known that Bruce Bensemann, a former lease holder, planted blue gum seedlings at the site of Munro's garden in the 1970s, but there was no trace of these at the time of our recent survey. Additionally, *Ulex europaeus* was recorded from the island in 1987 but was not observed on the recent expedition, causing hope that the rare occurrence has been eliminated.

Species of Conservation or Biogeographic Significance

There are four species from the island listed on schedule 5 of the Tasmanian *Threatened Species Protection Act* 1995. These are *Frankenia pauciflora, Agrostis aemula* var. *aemula, Chrysocephalum baxteri* and *Zygophyllum billardierei. Zygophyllum* is confined to calcareous sands on the south side of the island. *Frankenia pauciflora* is very localised on the northeast coast of Preservation Island. *Agrostis aemula* var. *aemula* was observed amongst granite boulders on the northern shore.

Chrysocephalum occurs predominantly on the eastern end of the island in *Ozothamnus turbinatus–Olearia axillaris* heathland. *Threlkeldia diffusa* is confined in Tasmania to the shores of Bass Strait. *Threlkeldia* is locally common, especially in one wind-damaged patch of *Ozothamnus turbinatus* shrubland. The species is highly susceptible to grazing, and on some of the islands in the Furneaux Group, which have had sheep, its abundance has clearly been reduced to the point where it only survives in sites totally protected from grazing.

A specimen of *Lepidium hyssopifolium,* collected by J. Whinray from Preservation Island, is lodged in the National Herbarium of Victoria (MEL). It is a species which is endangered at both state and national levels. The specimen was confirmed by N. Scarlett on 14 August 1981. Other congeners are more common throughout Bass Strait Islands, particularly in bird rookeries. We note that

Robinson *et al.* (1996) recorded the species on Dog Island and Masillon Island, two of the far west coast islands of South Australia.

Plants indicating particular environments are given in table 1. Our observations are consistent with associations reported elsewhere on Bass Strait Islands and coasts.

CONSERVATION VALUES OF THE FLORA AND VEGETATION

The island has populations of the following species which are highly restricted in Tasmania: *Threlkeldia diffusa, Zygophyllum billardierei, Frankenia pauciflora, Chrysocephalum baxteri* and *Lepidium hyssopifolium* (J. Whinray collection).

In a statewide context, the *Sydney Cove* Historic Site contributes best to the reservation status of *Atriplex cinerea* shrubland (Kirkpatrick *et al.* 1995) but is also important (table 2) for having examples of two poorly reserved or unreserved floristic communities.

TABLE 1
Some species strongly associated with particular environments

Species associated with limestone or calcareous soils
- *Threlkeldia diffusa*
- *Zygophyllum billardierei*
- *Lagurus ovatus*
- *Chenopodium murale*
- *Myoporum insulare*

Species associated with highly exposed rocky shorelines
- *Disphyma crassifolium*
- *Frankenia pauciflora*
- *Sarcocornia quinqueflora*
- *Leucophyta brownii*
- *Austrostipa stipoides*

Species associated with muttonbird rookeries
- *Atriplex cinerea*
- *Carpobrotus rossii*
- *Brachyscome diversifolia*

Species associated with rock slabs and boulder outcrops
- *Crassula sieberana* subsp. *tetramera*
- *Microsorum pustulatum*
- *Asplenium obtusatum*
- *Calandrinia calyptrata*
- *Bulbine semibarbata*
- *Dianella brevicaulis*

Species of sandy shores
- *Euphorbia paralias*
- *Cakile edentula*
- *C. maritima*
- *Austrofestuca littoralis*
- *Spinifex sericeus*

DISCUSSION

The most intriguing aspect of Preservation Island's vegetation is the degree to which it has changed since 1797. To assess change it is necessary to reconstruct the vegetation by using historical evidence or indications drawn from the present components of the flora, and by extrapolating from vegetation on other islands, allowing for differences in size, topographic variation, degree of exposure to the westerlies and the proximity of Preservation Island to larger land areas.

The historical record is patchy, but we know that the extent of the muttonbird rookery was far greater than it is today, while there are conflicting indications as to how wooded the island was. Some observers indicate the island as being covered in barilla, nettles and grass, all short vegetation. Other indications point to a much more wooded island, e.g. the advice to Baudin (his journal 10 March 1802, Cornell 1974) that the island had plenty of wood, the construction of a wooden hut by the *Sydney Cove* shipwreck survivors (Cumpston 1973).

TABLE 2
Native floristic plant communities recorded on Preservation Island and their conservation status*

Lilaeopsis polyantha herbfield
- unreserved
- <10m², very tiny patches in coastal soaks, badly degraded, outside Historic Site

Distichlis distichophylla closed grassland
- poorly reserved
- 0.5ha, excellent condition

Atriplex cinerea shrubland
- well reserved
- excellent condition, most in historic site

Spinifex sericeus–Austrofestuca littoralis grassland
- well reserved
- excellent condition, newly establishing

Myoporum insulare–Alyxia buxifolia–Correa alba heath
- well reserved
- good condition; a small number of exotic species

Austrostipa stipoides–Disphyma crassifolium tussock grassland
- well reserved
- good condition but accessed by cattle

Leucopogon parviflorus–Lobelia alata–Isolepis nodosa shrubland
- well reserved
- tiny fragments within the coastal fringe zone

* (Kirkpatrick *et al.* 1995)

The present composition of the vegetation indicates a few species which could form tall dominants of tall scrub or low closed forest, including *Allocasuarina verticillata, Myoporum insulare, Bursaria spinosa,* and *Leptospermum laevigatum.* Apart from *Myoporum insulare,* the others are now very restricted. She-oak *(Allocasuarina verticillata)* was a dominant species of the vegetation in the 1820s but by 1979 only three specimens (one of them dying) were observed, and more recently only one specimen has been observed (pl. 3). All of the above species are obligate seeders which would be disadvantaged by a high fire frequency, i.e. two or three fires in rapid succession would cause their local extinction. It is hardly conceivable that these tree species were not more widespread prior to European contact. There is much more potential suitable habitat on the island.

The extrapolation from other islands is useful. Forsyth Island, which is low and sandy and has been little disturbed, has a shrubby vegetation dominated by *Olearia axillaris* and *Ozothamnus turbinatus* with patches of *Leptospermum laevigatum* and *Myoporum insulare* up to 5 m height. It is a similar size to Preservation Island. Adjacent to Forsyth, Passage Island, which is on granite, has dense scrub (potential forest) with trees such as *Callitris rhomboidea, Allocasuarina verticillata, Leptospermum laevigatum* and *Melaleuca ericifolia.* The larger islands of the Outer Furneaux mostly have relictual stands or individuals of tree species. Eucalypts are the rarest group, being confined to Big Dog, Prime Seal and the Inner Sister Islands. *Myoporum insulare* occurs on many of the islands and is capable of forming a tall shrubland. *Allocasuarina verticillata,* a common component of the island floras capable of forming dense, low, closed, tiny relict stands in fire refugia, is on islands such as Badger, Big Dog and Inner Sister.

Preservation is within both the size range of these islands and the range of proximity to a larger land mass. Intriguing to note is the remnant of a post, protruding from a cairn on the high point on the western end of the island. This was examined in 1987 and appeared to be a spar of *Callitris.* If this was cut by Stokes' party as part of a trigonometrical survey arrangement, the spar would have been cut from whatever was available at the time. If a driftwood piece had been used, it is hardly likely to have lasted over 150 years. *Callitris,* if cut green, is likely to last this long, because of the special properties of the timber oils.

From the earliest days of European settlement fires may have been lit to help clear scrub for ease of access to lookout points and mutton bird burrows. The vegetation on Preservation Island is buffeted by strong prevailing winds. If fires were lit, there is a high chance that the winds would drive such fires right across the island, since there is very little topographic impediment. Obligate seeders would have suffered, if fires were months or one or two years apart. Such species would have fared worst on the granite substrate on the larger part of the island, west of the sandy areas. Here soil accumulation resulting directly from granite weathering would have been minimal, mainly resulting from the slow deposition of organic matter. As shrubland grew to scrub, provided there was a sufficient fire-free interval, this build up would have been enough to support closed scrub or low closed forest, with moisture retention being assisted by the shading from the vegetation canopy. Once this vegetation was destroyed by a major fire and the organic soil burned away, the succession to low closed forest would have been very slow and would have relied on a long fire-free interval, perhaps 40–50 years. However, since it is almost certain that the fire frequency increased dramatically after European contact, this would not have occurred. This assumption of increased frequency is based on archaeological evidence that there were no humans occupying the Furneaux Islands prior to this time (Sim & Gait 1992). Therefore, the fires occurring during this period could only have been caused by lightning strikes and very rare (Jackson 1999).

On the sandy soils at the eastern end of the island, there would have been more chance of obligate seeders surviving, because of the greater depth of soil and the distribution of seed throughout a large part of the soil profile by bioturbation. This may explain the persistence here of *Acacia sophorae* (pl. 5), as Kirkpatrick (1993) suggested that this species is readily killed by fire but germinates prolifically afterwards from the store of hard-coated seeds in the soil. There is an analogy between the processes which are likely to have happened on this island and the successional pathways to rainforest in western Tasmania. On quartzites, rainforest is able to exist on humic soils which have accumulated from vegetation through the slow successional path. After a hot fire in which the vegetation and soil have been consumed, a long period is required for the vegetation to proceed to a scrub, let alone to rainforest. On deeper mineral soils, there may be more likelihood of a faster succession.

A clue to the former vegetation of the island is found in a watercolour sketch by Laing in 1831 (reproduced opposite p98 in Plomley 1987) which shows some distinctive slender trees on the skyline, the same skyline which is now devoid of vegetation taller than *Poa* tussocks. Dismissing these trees as an artist's whimsy would not be consistent with the faithful rendering of the remaining background scene, the shapes and position of boulders for example. A most likely explanation for these trees is that they were remnants of the *Bursaria spinosa* component of the original scrub/low closed forest. *Bursaria spinosa* has persisted in grazing areas in other parts of Tasmania long after the rest of the original vegetation has been eliminated. The forms of some *Bursaria* remnants in pasture clearly correspond very well with the painted images from 1831.

The tea tree remnants of >4 m surrounding Munro's cottage at the time of Laing's painting were likely to be remnants of the original scrub.

Evidence indicates that attrition of tall scrub and low forest occurred rapidly after 1797. The goats kept by Munro ranged freely and would have wrought destruction on the native vegetation. They are capable of breaking down limbs of tall shrubs. *Bursaria spinosa* is highly palatable to goats, and the specimens in Laing's painting probably represent remnant individuals of a species formerly more widely spread. Once the vegetation became opened up by fire and other disturbances, the salt-laden westerlies would have made re-establishment very difficult. Preservation Island is one of the more highly modified of the Outer Furneaux Islands. *Allocasuarina verticillata* is especially targeted by goats (Harris & Wapstra 1999), so the goats on the island would have had a great impact on this species as well as others. Use of timber for building and for cooking fires would have added to the pressure on trees.

Early land use no doubt led to depletion of soils through burning, stock trampling and subsequent wind erosion, once the vegetation structure was opened up through fire and mechanical damage. The deterioration in soil quantity and extent would have meant ground unsuitable for

continued occupation by burrowing seabirds, in turn exacerbating the loss of nutrient bound up in the organic horizon of the soil.

If we assume that only the native species now present on the island were the same component as at contact, then obviously significant changes have occurred. Historical observers mention the abundance of barilla, especially in the 1830s. This species is favoured by disturbance and is a common component of seabird rookeries in Bass Strait. It is confined to a few localised patches and has clearly been reduced in parallel with the decline in the once extensive muttonbird rookery. It is clear that an outstanding and remarkable feature of the island in earliest times was the extent of this rookery, which was claimed to cover almost the whole island. Rookeries can be sustained in many vegetation types. In a closed scrub, the birds will travel along pathways on the ground until they reach a suitable launching point. The critical requirement is sufficient depth of soil, although dense growths of *Tetragonia implexicoma* or *Rhagodia candolleana* can provide burrows, especially where there is additional protection from a shrub or scrub canopy. Dense old *Poa poiformis* tussocks would also have been able to provide some burrow opportunities, since they form thick trunks, and the decaying older leaves form deep composting layers which can provide some protection.

Coasts and small islands have their terrestrial biological productivity boosted considerably by shore drift of algal wrack and carrion and through colonies of seabirds; such marine input has been found to produce most of the biomass and energy for islands (Polis & Hurd 1996). The perimeter to area ratio, for example, is a good predictor of arthropod density on islands that have been studied elsewhere. The importance of the energy input from the sea and seabirds cannot be underestimated for an island such as Preservation Island. The island's inherently low primary productivity, due to the very low rainfall and the low nutrient productivity of the granite soils, has been significantly boosted. The dense scrub and the huge numbers of seabirds occupying the island at European contact represent the accumulation of biological capital over thousands of years. Most of this capital appears to have been depleted in the first thirty or forty years following the discovery of the island.

VEGETATION MANAGEMENT

Conservation work on Preservation Island is important for the nature conservation values on the island and can also help the condition of other nearby islands. Control or eradication of the populations of *Euphorbia paralias* and *Lycium ferocissimum* on the island will reduce the source of propagules for further invasion.

The recommendations for maintaining and enhancing vegetation values, in priority order are as follows:
(1) continuing eradication of boxthorn; the programme being carried out by the Preservation Island Unit Trust needs to be supplemented by efforts from the Department of Primary Industries, Water and Environment on the Historic Site;
(2) removing sea spurge by appropriate methods;
(3) poisoning thistles;
(4) reducing stock impact on coastal soaks and springs by engineering better confined access to water, and by fencing;
(5) ensuring stock remain confined to the grasslands;
(6) germination from local seed and then planting of *Allocasuarina verticillata* and *Bursaria spinosa* in degraded areas, e.g. around the hut; *Callitris rhomboidea*, germinated from seed collected on Clarke Island, could also be planted in the grassland and hut zone.
(7) developing a fire management plan; and
(8) maintaining vigilance against new weed introductions; searching the area between the jetty and the hut for gorse, destroying any which are found.

The timetable for carrying out these recommendations and the specific methods for implementing them are being considered in the management plan at present being prepared for the island (Nicholas D'Antoine, pers. comm.)

ACKNOWLEDGEMENTS

We thank the Preservation Island Unit Trust, who generously allowed the use of their comfortable hut. Nicholas D'Antoine of the Trust assisted with information about management of the island. We also thank Mike Pemberton for taking care of the logistical arrangements and Sam Bayley of Flinders Island, Chris Grose, Paul Pohlner and Mike Nash for useful discussion. The Special Projects Section of the Department of Primary Industries, Water and Environment prepared the map. The assistance of Alex Buchanan and Dennis Morris of the Tasmanian Herbarium for species identification is much appreciated. Cathryn Coles of the National Herbarium of Victoria was also very helpful in discussing relevant collections in that institution.

REFERENCES

Begg, A.C. & Begg, N.C., 1979: *THE WORLD OF JOHN BOULTBEE.* Whitcoulls. Christchurch.

Buchanan, A.M., 1999: *A CENSUS OF THE VASCULAR PLANTS OF TASMANIA.* 3rd edn. *Tasm. Herb. Occ. Publ.* 6.

Campbell, J., 1828: Account of the group of islands situated in Bass Strait generally known in the charts by the name of Furneaux Islands. Hobart Town August 1828. (ms in Mitchell Library, Sydney).

Carcaillet, C., 1993: Les plantes allochtones envahissantes de l'archipel Crozet, Océan Austral. *Rev. Ecol.* (*Terre Vie*) 48: 3-20.

Collins, D., 1802: *AN ACCOUNT OF THE ENGLISH COLONY IN NEW SOUTH WALES. VOL. II.* (Republished by the Royal Australian Historical Society, Sydney, Fletcher, B.H., Reed, A.H. & Reed, A.W. [Eds], 1975.)

Cornell, C. (Ed.), 1974: *THE JOURNAL OF POST CAPTAIN NICHOLAS BAUDIN.* Libraries Board of South Australia.

Cumpston, J.S., 1973: *FIRST VISITORS TO BASS STRAIT.* Roebuck. Canberra.

Flinders, M., 1801: *OBSERVATIONS ON THE COASTS OF VAN DIEMEN'S LAND, ON BASS'S STRAIT AND ITS ISLANDS, AND ON PART OF THE COASTS OF NEW SOUTH WALES*; Intended to accompany the charts of the late discoveries in those countries. John Nichols, London.

Flora Advisory Committee, 1994: NATIVE HIGHER PLANT TAXA WHICH ARE RARE OR THREATENED IN TASMANIA. Edn 1. Species at Risk, Tasmania — flora. Parks and Wildlife Service, Tasmania.

FOWLER, R.M., 1980: *THE FURNEAUX GROUP BASS STRAIT. A HISTORY.* Vol. 1. Roebuck.

HARRIS, S. & BALMER, J., 1997: The vegetation and flora of Three Hummock Island, Western Bass Strait. *Pap. Proc. R. Soc. Tasm.* 131: 37–56.

HARRIS, S. & DAVIS, G., 1995: The vegetation and flora of Deal Island, Kent Group. *Pap. Proc. R. Soc. Tasm.* 129: 43–51.

HARRIS, S. & KIRKPATRICK, J.B., 1996: The coastal vegetation of northeast Tasmania. *Rec. Queen Vic. Mus.* 103: 121–131.

HARRIS, S. & WAPSTRA, H., 1999: The impact of feral goats on Tasmanian vegetation. Unpubl. rep. Dep. Primary Industries, Water and Environment.

HEYLIGERS, P., 1987: Strandline plants: invaders from overseas. *Wildl. Aust.* Spring 1987: 19–20.

HOPE, J.H., 1972: Bass Strait, its coasts and islands: a symposium. *Proc. R. Soc. Vict.* 85(2).

HOPE, J.H., MURRAY-SMITH, S. & NORMAN, F.T., 1973: Bibliography of Bass Strait 1797–1971. *Proc. R. Soc. Vict.* 85: 79–116.

HUNTER, J.T., 1998: Granite outcrop vegetation of Wilsons Promontory. *Vic. Nat.* 115(6): 322–325.

JACKSON, W.D., 1999: The Tasmanian environment. *In* Reid, JB., Hill, R.S., Brown, M.J & Hovenden, M.J. (Eds): *VEGETATION OF TASMANIA. Flora of Australia Suppl. Ser.* 8. ABRS: Ch. 2, 11–38.

JETSON, T., 1996: An island of contentment? A history of Preservation Island. *Pap. Proc. Tasm. Hist. Res. Assoc.* 43(1): 29–46.

KIRKPATRICK, J.B., 1993: Dry coastal ecosystems of southeastern Australia. *In* van der Maarel, E. (Ed.): *ECOSYSTEMS OF THE WORLD 2B: DRY COASTAL ECOSYSTEMS AFRICA, AMERICA, ASIA AND OCEANIA.* Elsevier, Amsterdam: Ch. 19.

KIRKPATRICK, J.B., BARKER, P., BROWN, M.J., HARRIS, S. & MACKIE, R., 1995: The Reservation Status of Tasmanian Vascular Plant Communities. *Wildl. Sci. Rep.* 95/4. Parks and Wildlife Service, Tasmania.

KOSTOGLOU, P., 1996. Sealing in Tasmania Historical Research Project. A report for the Parks and Wildlife Service.

MUELLER-DOMBOIS, D. & ELLENBERG, P., 1974: *AIMS AND METHODS OF VEGETATION ECOLOGY.* Wiley, New York.

MURRAY-SMITH, S., 1979: *MISSION TO THE ISLANDS. The missionary voyages in Bass Strait of Canon Marcus Brownrigg 1872–1885.* Cat and Fiddle Press, Hobart.

NASH, M., 1996: *CARGO FOR THE COLONY. The wreck of the merchant ship* Sydney Cove. Braxus Press, Sydney.

OPPERMANN, A., 1996: *COASTAL DUNE AND CLIFFTOP SURVEY: PROGRESS REPORT. Stage 1 Nullarbor and North-West Eyre Peninsula.* Coastal Management Section, South Australian Department of Environment and Natural Resources.

OPPERMANN, A., 1997: *COASTAL DUNE AND CLIFFTOP SURVEY: PROGRESS REPORT. Stage 2 Spencer Gulf, Kangaroo Island, and South East.* Biological Survey South Australia, Adelaide.

PARKES, J., HENZELL, R. & PICKLES, G., 1996: *MANAGING VERTEBRATE PESTS: FERAL GOATS.* Australian Government Publishing Service, Canberra.

PLOMLEY, N.J.B. (ED.) 1966: *FRIENDLY MISSION. THE TASMANIAN JOURNALS AND PAPERS OF GEORGE AUGUSTUS ROBINSON, 1829–34.* Tasmanian Historical Research Association, Hobart.

PLOMLEY, N.J.B., 1983: *THE BAUDIN EXPEDITION AND THE TASMANIAN ABORIGINES 1802.* Blubber Head Press, Hobart.

PLOMLEY, N.J.B., 1987: *WEEP IN SILENCE.* Blubber Head Press, Hobart.

POLIS, G.A. & HURD, S.D., 1996: Linking marine and terrestrial food webs: allochthonous input from the ocean supports high secondary productivity on small islands and coastal land communities. *Am. Nat.* 147(3): 396–423.

ROBINSON, T., CANTY, P., MOONEY, T. & RUDDOCK, P., 1996: *SOUTH AUSTRALIA'S OFFSHORE ISLANDS.* Australian Heritage Commission, Canberra.

SIM, R. & GAIT, P., 1992: *SOUTHERN FURNEAUX ISLANDS ARCHAEOLOGICAL SURVEY: Stage two of the prehistoric and historic archaeological site recording project in the Furneaux Group, Bass Strait, Tasmania.* Tasmanian Environment Centre, Hobart: 6–7.

SPECHT, R.L., 1970: *VEGETATION OF SOUTH AUSTRALIA.* Government Printer, Adelaide.

STOKES, J.L., 1846: *DISCOVERIES IN AUSTRALIA*; With an account of the coasts and rivers explored and surveyed during the voyage of *HMS Beagle* in the years 1827-43. Vol. 1 pp420-427. London: T&W Boone.

WILLIS, J.H., 1953: Land Flora. *In* The Archipelago of the Recherché. *Aust. Geogr. Soc. Rep.* 1. Part 3a. Australian Geographical Society, Melbourne: 3-35.

(accepted 6 September 1999)

APPENDIX
Higher plant census for Preservation Island

Vouchers and other records:
HO = Voucher lodged at the Tasmanian Herbarium, Hobart;
MEL = Voucher exists at the National Herbarium of Victoria, Melbourne.

Conservation status codes (source: *Threatened Species Protection Act* 1995):
3 = Schedule 3 (Taxa of Flora and Fauna which are Endangered) *Threatened Species Protection Act* 1995.
5 = Schedule 5 (Taxa of Flora and Fauna which are Rare) *Threatened Species Protection Act* 1995.

Distribution codes: i= introduced to Tasmania (source: Buchanan 1999).

Community types:
1 = *Poa* tussock grassland
2 = *Isolepis nodosa* sedgeland
3 = Rookery vegetation
4 = *Ozothamnus turbinatus* - *Olearia axillaris* heathland/shrubland
5 = *Spinifex sericeus* grassland
6 = Bare granite slab and boulder communities
7 = *Acacia sophorae* closed scrub
8 = Wetlands, damp herbfields, soaks & moist halophytic grasslands and herbfields
9 = Coastal fringe vegetation
10 = *Austrostipa stipoides* tussock grassland
11 = *Lycium ferocissimum* shrubland
12 = *Leucophyta brownii* heath

Species abundance codes: r = rare; o = occasional; c = common.

		Where vouchered	Status/ distribution	Community Types 1	2	3	4	5	6	7	8	9	10	11	12
DICOTYLEDONAE															
AIZOCEAE															
Carpobrotus rossii	Pigface	HO		r	r	c	r	r	c		c	c	c	o	c
Disphyma crassifolium	Rounded noon-flower	HO		o	o	c	o		r	r	r	c	o	o	r
Tetragonia implexicoma	Iceplant	HO		o	o	c	o		r	r	r	c	o	o	r
APIACEAE															
Apium prostratum	Sea celery	HO		o	o	o	o				o	c	c	o	c
Lilaeopsis polyantha	Australian lilaeopsis										o				
APOCYNACEAE															
Alyxia buxifolia	Sea box	MEL					r		o			c			
ASTERACEAE															
Actites megalocarpa	Coastal sow-thistle	HO		r	r	o	r	c	r			o	r		r
Arctotheca calendula	Capeweed	HO	i	o											
Brachyscome diversifolia	Coastal tall daisy	MEL		o	o	c	o		o			o	o	o	
B. graminea	Grass daisy										o				
Carduus tenuiflorus	Winged slender thistle	HO	i	o	o										
Chrysocephalum baxteri	Fringed everlasting		5	r			o								
Cirsium vulgare	Spear thistle	HO	i	o	o										
Conyza spp.			i												
Cotula coronopifolia	Billy buttons	HO		c							c				
Cymbonotus preissianus	Bears ear	HO		r											
Gamochaeta purpurea	Purple cudweed	HO	i	o	o										
Gnaphalium indutum	Tiny cudweed	MEL													
Helichrysum leucopsideum	Satin everlasting	HO		o	o										
Hypochoeris radicata	Cats ear	HO	i	c	c		o	o	o		r	o	o	o	r
Leucophyta brownii	Cushion bush	MEL					r	r	o			c	o		c
Olearia axillaris	Coast daisy bush	HO					c	o							
Ozothamnus turbinatus	Coast everlasting						c	o							
Pseudognaphalium luteo-album	Jersey cudweed	HO		o							o		o		
Senecio hispidulus	Hill fireweed	HO													

		Where vouchered	Status/ distribution	Community Types 1	2	3	4	5	6	7	8	9	10	11	12
S. lautus	Variable groundsell	HO		o	o	c	o	r	o		o	o	o		r
Sonchus oleraceus	Common sowthistle	HO	i			o									
Vellereophyton dealbatum	White cudweed	HO	i	o	o		o		o						
BRASSICACEAE															
Cakile edentula	American sea rocket		i									o			
C. maritima	European sea rocket	HO	i									o			
Lepidium hyssopifolium	Peppercress	MEL	3												
J. Whinray collection: see text.															
CAMPANULACEAE															
Lobelia alata	Angled lobelia	HO		r					o		c	c	r		
CARYOPHYLLACEAE															
Cerastium sp.	Chickweed		i						r						
Colobanthus apetalus	Coast colobanth								r						
Polycarpon tetraphyllum	Four-leaf allseed	HO	i	c	c	c	r		c		c	r	r	r	
Sagina maritima	Sea pearlwort	HO	i									o			
Silene gallica	French catch-fly	HO	i	r											
CASUARINACEAE															
Allocasuarina verticillata	Drooping she-oak						r								
CHENOPODIACEAE															
Atriplex cinerea	Grey saltbush	HO				c					o	o			
A. prostrata	Mat saltbush		i						r		o				
Chenopodium murale	Nettle-leaf goosefoot		i	r											
C. pumilio	Small crumbweed			c	c							r		o	
Rhagodia candolleana	Coast saltbush	HO		o	o	c	o		o	c	o	o	r	c	o
Sarcocornia quinqueflora	Beaded glasswort	HO									c	c			
Suaeda australis	Seablite										o				
Threlkeldia diffusa	Coast bonefruit	HO					o								
CONVOLVULACEAE															
Dichondra repens	Kidney weed			c	c		c		r			r	c	c	r
CRASSULACEAE															
Crassula helmsii	Swamp stonecrop								o						
C. sieberana subsp. *tetramera*	Austral stonecrop								c						
EPACRIDACEAE															
Leucopogon parviflorus	Coastal beard heath	HO					c	o	r	c		r			o
Monotoca elliptica	Tree broom-heath						o								
EUPHORBIACEAE															
Euphorbia paralias	Sea spurge		i								o	c			
FABACEAE															
Medicago lupulina	Black medic	HO	i	o	o										
M. polymorpha	Burr medic	HO	i	o	o										
Melilotus albus	Bokhara clover		i	c	c							r	o	c	
Swainsona lessertiifolia	Poison pea								r			r			
Trifolium campestre	Hop clover	HO	i	r	r		r					r		r	
T. dubium	Yellow suckling clover	HO	i	r	r						r		r	r	
T. fragiferum	Strawberry clover		i	o											
Ulex europaeus	Gorse		i												
Vicia sativa	Common vetch	HO	i									o			
FRANKENIACEAE															
Frankenia pauciflora	Sea heath	HO	5									r			
GENTIANACEAE															
Centaurium erythraea	Common centaury		i	r	r									r	
Sebaea albidiflora	White sebaea	HO									r				
GERANIACEAE															
Erodium sp.	Stork's-bills		i	c	c							r		c	
Geranium molle	Dove's-foot crane's-bill		i								r	r			
G. potentilloides	Mountain geranium											r			
Pelargonium australe	Wild geranium			r											
LAMIACEAE															
Marrubium vulgare	Horehound		i	r											
MALVACEAE															
Lavatera plebeia	Austral hollyhock					r									

		Where vouchered	Status/ distribution	Community Types 1	2	3	4	5	6	7	8	9	10	11	12
MIMOSACEAE															
Acacia ?genistifolia	Early wattle						r		r					r	
Acacia sophorae	Coast wattle						r			c					
MYOPORACEAE															
Myoporum insulare	Boobyalla	HO		r	r		c		r					r	
MYRTACEAE															
Kunzea ambigua	Fringe myrtle	HO					r								
Leptospermum laevigatum	Coast tea tree						o								
ONAGRACEAE															
Epilobium billardierianum	Common willowherb			o	o		r	o				r		o	
OXALIDACEAE															
Oxalis perennans	Native oxalis			c	c									c	r
PITTOSPORACEAE															
Bursaria spinosa	Sweet bursaria						r					r			
PLANTAGINACEAE															
Plantago coronopus	Buckshorn plantain		i	c	c		o		c		c	c	c	c	o
POLYGALACEAE															
Comesperma volubile	Blue love creeper						o								
POLYGONACEAE															
Acetosella vulgaris	Sheep sorrel		i	c	c				c				r	c	
Muehlenbeckia adpressa	Climbing lignum						o		o			o			
Rumex bidens	Mud dock			o	o									o	
R. brownii	Slender dock			o	o									o	
PORTULACEAE															
Calandrinia calyptrata	Pink purslane								o						
PRIMULACEAE															
Anagallis arvensis	Scarlet pimpernel	HO	i	r	r								r	r	
Samolus repens	Creeping brookweed	HO									r				
RANUNCULACEAE															
Clematis microphylla	Small-leaf clematis											r			
ROSACEAE															
Acaena novae-zelandiae	Buzzy			o	o									o	
RUBIACEAE															
Coprosma repens	Mirror bush		i						r						
Galium australe	Tangled bedstraw								r						
RUTACEAE															
Correa alba var. *alba*	White correa	MEL					c		c			c			o
C. alba X *Correa backhouseana*		MEL													
C. reflexa var. *reflexa*	Common correa	MEL													
SANTALACEAE															
Exocarpos strictus	Dwarf cherry	HO					o								r
Leptomeria drupacea	Currant bush						o								
SCROPHULARIACEAE															
Mimulus repens	Creeping monkey-flower										o				
SOLANACEAE															
Lycium ferocissimum	African boxthorn		i	o	o		o				r	r	r	c	
Solanum nigrum	Black-berry nightshade		i	r	r				r					c	
THYMELAECEAE															
Pimelea serpyllifolia	Thyme rice-flower						c	o		o					
URTICACEAE															
Urtica urens	Stinging nettle		i	o	c									o	
ZYGOPHYLLACEAE															
Zygophyllum billardierei	Scrambling twin-leaf		5				r					r			
MONOCOTYLEDONAE															
CENTROLEPIDACEAE															
Centrolepis strigosa	Hairy centrolepis						r		r						
CYPERACEAE															
Isolepis aucklandica	Club-rush										r				
I. cernua	Grassy club-rush	HO		o							c	r			
I. nodosa	Knobby club-rush	HO		c	c		c	o			o	o	o	c	o

		Where vouchered	Status/ distribution	Community Types 1	2	3	4	5	6	7	8	9	10	11	12
Lepidosperma gladiatum	Coast sword sedge	HO		c	c		o			o		o			o
Schoenoplectus pungens	American club-rush	HO		r							o				
JUNCACEAE															
Juncus kraussii	Sea rush	HO		o	o						o				
J. pallidus	Pale rush			o											
LILIACEAE															
Bulbine semibarbata	Leek lily								c		o	o			
Dianella brevicaulis (Ostenf.) G.W. Carr & P.F. Horsfall	Coastal flax-lily								o						r
D. revoluta	Spreading flax-lily	HO		r			r								
D. tasmanica	Tasman flax-lily						r								
ORCHIDACEAE															
Microtis unifolia	Common onion orchid			c											
POACEAE															
Agrostis aemula var. *aemula*	Blown grass		5						r						
Aira caryophyllea	Silvery hair grass	HO	i	o			r								
A. praecox	Early hair grass		i						o						
Austrofestuca littoralis	Coast fescue	HO						c				r			
Austrostipa flavescens	Yellow spear grass	HO					o								
A. stipoides	Coastal spear grass	HO										o	c		
Bromus diandrus	Great brome	HO	i	c	c		r		r					c	
B. hordeaceus	Soft brome	HO	i	c	c									c	
Catapodium rigidum	Fern grass	HO	i	r	r		r		r					r	
Dactylis glomerata	Cocksfoot		i	r	r										
Dichelachne crinita	Long-hair plume grass			r			r		o				r		
Distichlis distichophylla	Australian salt grass	HO		o	o						c	c	o		
Holcus lanatus	Yorkshire fog grass	HO	i	r	r									r	
Hordeum murinum ssp. *glaucum*	Wild barley		i	r											
Lagurus ovatus	Hare's-tail	HO	i	c	c		c		o		r	c		c	o
Lolium perenne	Perennial ryegrass	HO	i								o				
Parapholis incurva	Curly ryegrass	HO	i						o						
Phragmites australis	Common reed	HO									r				
Poa poiformis	Blue tussock grass	HO		c	c	o	o		o	r	r	o		c	
Polypogon monspeliensis	Annual beard-grass		i	r											
Rytidosperma dimidiatum	Long-hair plume grass											r			
Spinifex sericeus	Coastal spinifex	HO						c							
Stenotaphrum secundatum	Buffalo grass		i	r											
PTERIDOPHYTA															
ASPLENIACEAE															
Asplenium obtusatum	Shore spleenwort	HO							r						
DENNSTAEDTIACEAE															
Pteridium esculentum	Austral bracken								r						
POLYPODIACEAE															
Microsorum pustulatum	Kangaroo fern								r						

THE CHARACTERISTICS AND MANAGEMENT PROBLEMS OF THE VEGETATION AND FLORA OF THE HUNTINGFIELD AREA, SOUTHERN TASMANIA

by J.B. Kirkpatrick

(with two tables, four text-figures and one appendix)

KIRKPATRICK, J.B., 1999 (31:x): The characteristics and management problems of the vegetation and flora of the Huntingfield area, southern Tasmania. *Pap. Proc. R. Soc. Tasm.* 133(1): 103–113. ISSN 0080–4703. School of Geography and Environmental Studies, University of Tasmania, GPO Box 252-78, Hobart, Tasmania, Australia 7001.

The Huntingfield area has a varied vegetation, including substantial areas of *Eucalyptus amygdalina* heathy woodland, heath, buttongrass moorland and *E. amygdalina* shrubby forest, with smaller areas of wetland, grassland and *E. ovata* shrubby forest. Six floristic communities are described for the area. Two hundred and one native vascular plant taxa, 26 moss species and ten liverworts are known from the area, which is particularly rich in orchids, two of which are rare in Tasmania. Four other plant species are known to be rare and/or unreserved in Tasmania. Sixty-four exotic plant species have been observed in the area, most of which do not threaten the native biodiversity. However, a group of fire-adapted shrubs are potentially serious invaders. Management problems in the area include the maintenance of open areas, weed invasion, pathogen invasion, introduced animals, fire, mechanised recreation, drainage from houses and roads, rubbish dumping and the gathering of firewood, sand and plants.

Key Words: flora, forest, heath, Huntingfield, management, Tasmania, vegetation, wetland, woodland.

INTRODUCTION

The Huntingfield Estate, approximately 400 ha of forest, woodland, heath and pasture to the west of Blackmans Bay, south of Hobart, Tasmania, was purchased by government for housing development. In 1997, most of the remaining natural vegetation in the Huntingfield Estate was proclaimed as the Peter Murrell Nature Reserve and Conservation Area.

Parts of this area have been subject to previous botanical surveys. Kirkpatrick 1977 sampled the heaths of the area and recommended that they be reserved as the only extensive example of the vegetation type near Hobart. Botanical surveys, concentrating on the Coffee Creek area, have been produced by Pyrke (1990) and Duncan & Duncan (1995). Ziegeler (1994) mapped the distribution of the threatened orchid, *Prasophyllum concinnum*, in Huntingfield.

The present paper documents the vegetation and the vascular and bryophytic flora of the area, and discusses vegetation management issues in a conservation context.

METHODS

A rough vegetation map of the estate was drawn up, using a corrected black and white aerial photograph mosiac. Approximately ten sampling locations were placed in each of five mapping units, using a table of random numbers. An extra two sampling sites were located subjectively within a small area of native grassland that was not recognised in the initial mapping. In addition, vascular plant species lists were made for the zones within the small, natural enclosed wetland on the estate.

At each sampling site a 10 x 10 m quadrat was laid out. All identifiable vascular plant taxa within this space were noted. The cross-sectional area of trees at 1.3 m (basal area) was measured using the Bitterlich variable radius technique (Mueller-Dombois & Ellenberg 1974). The height of the shrub stratum was measured using a tape. The cover of the shrub stratum was estimated using the following classes: <1%, 1–5%, 5–25%, 25–50%, 50–75%, 75–100%. The species with the most cover in the shrub stratum (dominant species) was noted. If another species had more than half the cover of the dominant one it was noted as a codominant. Altitude, slope (using a clinometer) and aspect (direction of slope, using a compass) were also noted for each quadrat.

While traversing the area from sample location to sample location and at other times, notes were made of the locations and extent of exotic species infestations and of the vegetation type. These observations and coloured aerial photographs (Hobart Area 11.3.95, run 4, 1234-101 and 1234-103) were used to refine the vegetation map and to produce a map of exotic plant infestations. Vegetation mapping seeks to draw boundaries around areas of relative uniformity in colour and texture on aerial photographs, or other imagery, then identify the vegetation characteristics that make each unit different. It does not necessarily result in units that fully correspond with the distributions of floristic groups, because the dominant species in the tree and ground layers do not necessarily control the overall floristic composition (Kirkpatrick & Dickinson 1986).

An initial sorted table of the species by site data was produced using a computer program, TWINSPAN (Hill 1979). This table was then sorted further to better reveal groups of quadrats with similar species composition and groups of species with similar quadrat distributions. The groups of quadrats are the floristic communities, which can be identified through the presence and absence of groups of species. These are not necessarily congruent with mapping units.

RESULTS

The Flora

Two hundred and one native vascular plant taxa have been recorded from the Huntingfield Estate in this and previous studies (appendix 1). Eleven (5.5%) of these taxa are endemic to Tasmania. The outstanding family in terms of numbers of native species is the Orchidaceae, with 35 species in the

area, including two Tasmanian endemics, *Prasophyllum concinnum* and *Caladenia atrata*. Twenty-six native moss species and ten native liverwort species have also been observed in the area by Tony Moscal (appendix 1). One of the moss species, *Archidium stellatum*, has not been previously known from Tasmania. However, its identification awaits confirmation.

Sixty-four exotic vascular plant taxa have been observed in the estate (appendix 1). Grasses (Poaceae) and daisies (Asteraceae) constitute a large proportion of these taxa.

The Plant Communities

Six floristically distinct communities were recognised from the sorted table (table 1). The distributions of the communities are shown in figure 1. The descriptions below indicate all species occurring in more than 60% of the quadrats in a particular group, grouped by lifeform. The term graminoid covers sedges, rushes, orchids, lilies and irids. The name of a floristic group includes the combination of species that best differentiate the group from others and the most common structural/dominance vegetation type. Similar vegetation types recognised in the literature are indicated.

Floristic Communities

(1) *Acacia genistifolia-Deyeuxia quadriseta-Goodenia lanata* heath/grassland

Trees: *Eucalyptus amygdalina*

Shrubs: *Acacia genistifolia, A. myrtifolia, Amperea xiphoclada, Epacris impressa, Gonocarpus tetragynus, Hibbertia riparia, Leptospermum scoparium, Leucopogon collinus, Styphelia adscendens*

Graminoids: *Hypolaena fastigiata, Lepidosperma concavum, Leptocarpus tenax, Schoenus lepidosperma*

Grasses: *Danthonia* spp., *Deyeuxia quadriseta, Ehrharta distichophylla, E. stipoides, Stipa* spp.

Herbs: *Goodenia lanata, Helichrysum scorpioides*

Ferns: *Pteridium esculentum*

Most similar vegetation type: *Lepidosperma concavum-Cassytha glabella-Gonocarpus tetragynus* heath (Kirkpatrick 1977)

This community is defined by the presence of species groups A and B and the absence of species groups C, F–H and J–N (table 1). It occurs in well-drained places where a fine-textured soil horizon is close to or at the surface. It lacks a dense shrub stratum and is relatively rich in grasses and herbs, possibly a reflection of a higher nutrient status of its soils than adjacent communities on deep sands. *Acacia genistifolia* is the most common dominant species. However, some quadrats in this groups are dominated by *Stipa mollis*, which is particularly striking during its flowering season. Trees, where they occur, are very sparse.

(2) *Eucalyptus amygdalina-Baeckea ramosissima-Tetratheca labillardierei* heathy woodland

Trees: *Eucalyptus amygdalina*

Shrubs: *Allocasuarina monilifera, Amperea xiphoclada, Aotus ericoides, Baeckea ramosissima, Bossiaea cinerea, Epacris impressa, Gonocarpus tetragynus, Leptospermum scoparium, Leucopogon collinus, L. ericoides, Pimelea linifolia*

Parasitic climbers: *Cassytha pubescens*

Graminoids: *Hypolaena fastigiata, Schoenus lepidosperma*

Herbs: *Stylidium graminifolium*

Ferns: *Pteridium esculentum*

Most similar vegetation types: Heathy *Eucalyptus amygdalina* coastal forest (Duncan & Brown 1985)

This community is defined by the presence of species in groups D–I and the absence of species in groups A, B and J–N (table 1). There are no species that are both largely confined to this community and present in most of its quadrats. This is the most widespread vegetation type in the estate. It is usually a woodland dominated by *E. amygdalina*, with a dense understorey of small-leaved shrubs and bracken less than 2 m tall. It occurs on well-drained sites on deep, leached sand.

(3) *Allocasuarina monilifera-Gymnoschoenus sphaerocephalus-Dillwynia glaberrima* heath

Trees: *Eucalyptus amygdalina*

Shrubs: *Allocasuarina monilifera, Amperea xiphoclada, Aotus ericoides, Baeckea ramosissima, Bossiaea cinerea, Dillwynia glaberrima, Epacris impressa, E. lanuginosa, Hibbertia acicularis, Leptospermum scoparium, Leucopogon collinus, L. ericoides, Pimelea linifolia*

Parasitic climbers: *Cassytha glabella, C. pubescens*

Graminoids: *Gymnoschoenus sphaerocephalus, Hypolaena fastigiata, Lepidosperma filiforme, Leptocarpus tenax*

Herbs: *Stylidium graminifolium*

Ferns: *Pteridium esculentum*

Most similar vegetation type: *Schoenus lepidosperma-Epacris lanuginosa-Empodisma minus* heath (Kirkpatrick 1977)

This community is defined by the presence of species in groups D–J and the absence of species in groups A–C and K–N. There are no species that are both largely confined to this community and present in most of its quadrats. The community consists mostly of heath, marginal to sedgeland. It occurs on more poorly-drained sites than the heaths in group 1. Trees, where present, are usually sparse.

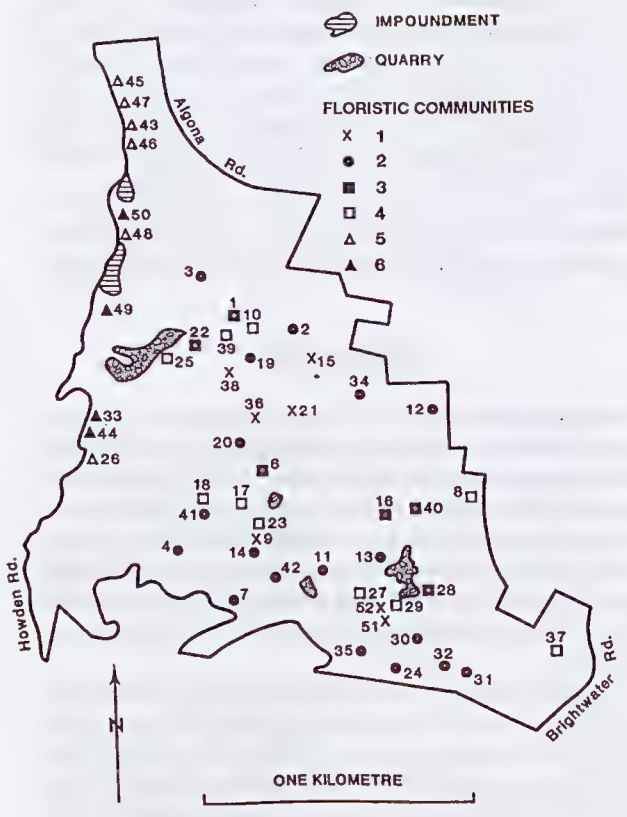


FIG. 1 — The distribution of quadrats in the six floristic communities

(4) *Melaleuca squarrosa-Gymnoschoenus sphaerocephalus-Gleichenia dicarpa* sedgeland/heath/fernland
Trees: *Eucalyptus amygdalina*
Shrubs: *Aotus ericoides, Dillwynia glaberrima, Epacris lanuginosa, Leptospermum scoparium, Melaleuca squarrosa, Sprengelia incarnata*
Graminoids: *Gymnoschoenus sphaerocephalus, Leptocarpus tenax, Lepyrodia tasmanica, Patersonia fragilis, Schoenus lepidosperma*
Ferns: *Gleichenia dicarpa, Pteridium esculentum, Selaginella uliginosa*
Most similar vegetation type: Lowland eastern sedgey buttongrass moorland (Jarman *et al.* 1988)

This community is defined by the presence of species in groups D–L and the absence of species in the other groups (table 1). *Melaleuca squarrosa* and *G. dicarpa* are both abundant in this group and largely absent from others. These two species and *Gymnoschoenus sphaerocephalus* are the most frequent dominants. The community occurs in flat areas along stream lines, where drainage is poor. Trees are sparse or absent. Given a long period without fire *M. squarrosa* could form a closed-scrub on most sites on which this community occurs.

(5) *Eucalyptus amygdalina-Acacia melanoxylon-Oxylobium ellipticum* open-forest
Trees: *Acacia melanoxylon, Eucalyptus amygdalina*
Shrubs: *Amperea xiphoclada, Aotus ericoides, Leptospermum scoparium, Melaleuca squarrosa, Oxylobium ellipticum, Pimelea linifolia,*
Herbs: *Stylidium graminifolium*
Ferns: *Pteridium esculentum*
Most similar Statewide vegetation type: Shrubby *Eucalyptus amygdalina* forest (Duncan & Brown 1985)

This community is defined by the presence of species in groups H, I, L and M and the absence of species in other groups (table 1). *Acacia melanoxylon* and *O. ellipticum* are both abundant in this group and largely absent from others. *E. amygdalina* and, to a lesser extent, *E. obliqua, E. viminalis* and *E. ovata* form a tall tree layer, below which there is a sparser short tree layer dominated by *Acacia melanoxylon.* The ground stratum is a depauperate heath. The community occurs on usually well-drained sites on deep, infertile sand in situations where moisture is augmented by downslope flow.

(6) *Eucalyptus viminalis-E. amygdalina-Senecio* spp. open-forest
Trees: *Eucalyptus viminalis, E. amygdalina*
Shrubs: *Pimelea linifolia*
Herbs: *Senecio* spp.
Ferns: *Pteridium esculentum*
Most similar vegetation type: Shrubby *Eucalyptus amygdalina* forest (Duncan & Brown 1985)

This community is defined by the presence of species in groups I, and L–N and the absence of species in other groups (table 1). *E. viminalis* and *Senecio* spp. best define the group. *E. viminalis, E. amygdalina* and *E. ovata* dominate the tree canopy in various combinations. There is a sparse taller shrub layer with the ground layer being dominated by a mixture of shrubs, graminoids, herbs and grasses. This community occurs along the Coffee Creek Valley, and is often badly invaded by exotic species.

Vegetation Types

The mapped vegetation types are described below. Their distributions are shown in figure 2.

(1) *Eucalyptus amygdalina-E. viminalis-E. obliqua* shrubby forest

This unit includes most of floristic communities 5 and 6, with the exception of areas dominated by *E. ovata.* Its characteristics and environment are described under these floristic communities. In general, it best fits shrubby *E. amygdalina* forest (Duncan & Brown 1985) among previously described communities. Small areas within this mapping unit belong to *E. viminalis-Bedfordia salicina-Pultenaea juniperina* wet sclerophyll forest and *E. obliqua-Olearia lirata-P. juniperina* wet sclerophyll forest (Kirkpatrick *et al.* 1988). These wet sclerophyll forest areas were insufficiently extensive to have a good chance of being selected in the random choice of quadrats, and what chance they had failed to be realised.

(2) *Eucalyptus ovata* shrubby forest

This unit occurs in the most poorly drained situations within the shrubby forest of floristic communities 5 and 6. *Melaleuca squarrosa* is prominent in the understorey. Herbs and grasses occur in the ground layer, which has much bare ground. The most similar recognised community is the grassy *E. ovata* woodland of Duncan & Brown (1985).

FIG. 2 — Natural vegetation map of the Huntingfield Estate. 1 = Eucalyptus amygdalina–E. viminalis–E. obliqua *shrubby forest; 2* = E. ovata *shrubby forest; 3* = E. amygdalina *heathy coastal forest/woodland; 4* = E. amygdalina *heathy forest on sandstone; 5 = open heath; 6 = closed heath; 7 = sedgeland; 8 = grassland; 9 = wetland.*

TABLE 1.
Sorted table for species occurring in three or more quadrats from the Huntingfield Estate

	3 12355 6951821	134 442223	11123333412 712340145190	124 2 668012	312223112 8703799785	244444 636875	3445 3490
Community	1		2	3	4	5	6
Acacia myrtifolia	1-111--	11-1-	----------	------	----------	------	----
Acacia suaveolens	-11----	-1-	----------	------	----------	------	----
Deyeuxia quadriseta	1111-11		----------	------	----------	------	----
Goodenia lanata	1111-11	11-	----------1---	------	----------	------	----
A *Hibbertia riparia*	1--11--		----------	--1---	----------	------	----
Stipa spp.	-11-111	-1-	----------	------	----------	------	----
Ehrharta stipoides	11-1---		----------	------	----------	------	----
Danthonia spp.	11--111	11-	----------1----	------	----------	------	----
Helichrysum scorpioides	-1111--	11-	----------1----	-1----	----------	------	----
Lepidosperma concavum	-111---	11-1-	--------1----1	------	----------	------	----
Eriochilus cucullatus	-1-----	1-	----------	1-----	----------	------	----
B *Acacia genistifolia*	1111111	11-1-	----------1--1	------	---1------	------	----
Ehrharta distichophylla	-111111	------	1------11---	-1----	1---------	------	----
Leptomeria drupacea	---1---	---1-	----------	------	1---------	------	----
Dianella revoluta	-1---11	1--1-	----------	------	----------	------	1---
Exocarpos cupressiformis	-------	-11-	------1-1------	------	----------	------	----
C *Pterostylis* spp.	-------	1-11-	----------	------	----------	------	----
Tetratheca labillardierei	-------	---1-	-111-11------	----1-	----------	------	----
Styphelia adscendens	1111111	1--1-	--1-11111	11-1--	----------	1-----	----
Baeckea ramosissima	-1--1-1	-1-111-	111111-11--	1-1-11	-----1----	------	----
D *Allocasuarina littoralis*	11-----	1111-11-	-------11--	-11--1	----------	------	----
Hypolaena fastigiata	-111111	111-1-	-1111-11111-	111--1	---------1	------	----
Banksia marginata	-1--1-1	--11-1-	--1--------	-1--11	------1--1	------	----
Gonocarpus tetragynus	1111111	11111-11-	--1-11111	-1-11-	1--1-1----	----1-	--1-
E *Leucopogon collinus*	1111111	1111-11-	1111111111	111111	---1-1-111	------	----
Schoenus lepidosperma	1-11111	1---11-	1-1-1-11111	1-11--	-1-11-111-	------	----
Leptocarpus tenax	1-1-111	----111-	-1-1---111	111111	1111111-11	-11---	----
Allocasuarina monilifera	----11-	1--11-	-11111111-11	111111	-----1----	------	----
Hibbertia acicularis	-------	11-11-	-1-1-1-1--	11-11-	----------	------	--1-
Bossiaea cinerea	-1-----	111111	1111111111-11	1111-1	---1-1----	------	1-1-
F *Gahnia radula*	-----11	1111--	11-1111-1---	-111--	1----1----	------	----
Leucopogon ericoides	1------	1111-11	111--111--1	111111	---------1	-1-1--	----
Leucopogon virgatus	---1---	----1-	-11-11-----1	----1-	---------1	------	----
Cassytha glabella	------1	11---1-	1--1-------	111-1-	--11------	------	----
Persoonia juniperina	--1-11-	111----	1-1----111-	--111-	-----1----	1-----	----
Gompholobium huegelii	-------	11-111-	--1-1---111	--11--	--1111---1	------	----
G *Dillwynia glaberrima*	--1----	11-11-	-1-----1111-	1-1111	1-1--11111	------	----
Restio monocephalus	-------	-------	111-----11-	1---11	-------11-	1-----	----
Cassytha pubescens	1------	1111-11	1111111111--	1-1-11	-11----1-1	111---	----
H *Aotus ericoides*	-------	1-11111	1111111111	1-1111	--1-11-111	1-111-	----
Stylidium graminifolium	------1	1111111	--111111111	111111	--11-1-11-	111-11	-11-
Eucalyptus amygdalina	-11-11-	111111	1111111111111	111111	11-1--111-	11-11-	1-11
Pimelea linifolia	-11----	1-11--	11--111-1111	11111-	---11---1-	11111-	11-1
I *Leptospermum scoparium*	1111111	111111	1111111111111	111111	1111111111	11-1-1	-1--
Amperea xiphoclada	--111--	111111	111111111111-11	1-111-	----1--11-	11--11	-11-
Epacris impressa	-1111--	1111-11	1111111111111	111111	---111----	-11-1-	-1--
Pteridium esculentum	11111--	11-1111	-1111111-11	-111-1	--11111--1	111111	1111
Gymnoschoenus sphaerocephalus	-------	-------	----------	111111	1111111111	------	----
Melaleuca squamea	-------	-------	----------	----11	--1-11-1-1	------	----
Sprengelia incarnata	-------	-------	----------	--1-11	-11-11-11-	------	----
J *Lepyrodia tasmanica*	-------	-------	----------	--1-11	11111111--	------	----
Epacris lanuginosa	-------	-------	----------	-11-11	111111111-	1-----	-1--
Lepidosperma filiforme	--11---	---------1--------		1111--	11-111----	------	----
Patersonia fragilis	--1-1--	----------	----------11	-1--1-	111111----	------	----
Selaginella uliginosa	-------	----------	----------1-1	-1-1--	11-1-1-11-	------	----
Lomandra longifolia	-------	--11-	----------	------	--11------	------	11--
Stypandra caespitosa	-------	1-	----------1	1-----	---1---11-	------	----
K *Eucalyptus tenuiramis*	-------	-------	----------	--1---	--1-11----	------	----
Xyris operculata	-------	-------	----------	------	1--11---1-	------	----
Gleichenia dicarpa	-------	-------	----------	--1---	-111111--1	------	----
Empodisma minus	-------	-------	----------	----1-	--1-111---	-----1	----

TABLE 1 cont.

	3 12355 134 11123333412 124 2 312223112 244444 3445 6951821 442223712340145190 668012 8703799785 636875 3490
Melaleuca squarrosa	------- ---------- -11--- 111-111111 1111-1 -1-1
L *Hibbertia procumbens*	------- -------1---------- --1--- -------1-- -11--- --1-
Boronia parviflora	------- ---------- ------ 11-------- ------ -1--
Acacia melanoxylon	------- ---------- ------ ---------- 11-111 --1-
Oxylobium ellipticum	------- ---------- ------ --1------- 111--1 ----
M **Ulex europaeus*	------- ---------- ------ ---------- -11--- ---1
Dianella tasmanica	------- ---------- ------ --1------- -----1 -1--
Eucalyptus ovata	------- ---------- ------ ---------- 1----- -1-1
Poa spp.	------- ---------- ------ ---------- ---11- -11-
Senecio spp.	------- ---------- ------ ---------- ------ 11-1
N *Eucalyptus viminalis*	------- ---------- ------ ---------- 1----- 1111
**Rubus fruticosus*	1------ ---------- ------ ---------- -1---- 1--1
**Holcus lanatus*	1------ ---------- ------ ---------- ------ 11--

* Introduced species.

TABLE 2
Vascular plant communities noted from Huntingfield Estate and their reservation status*

Mappable plant communities†	% of original area reserved	Status‡
Lowland tussock grassland	<1	PR
Heath	15	WR
Buttongrass moorland	50	WR
Enclosed non-glacial wetland	8	PR
Eucalyptus obliqua wet sclerophyll forest	4	PR
Coastal *E. amygdalina* dry sclerophyll forest	6	PR
E. amygdalina dry sclerophyll forest on sandstone	<1	PR
Inland *E. tenuiramis* dry sclerophyll forest	<1	PR
E. ovata forest	<1	PR

Described plant communities†	Status‡
Eucalyptus viminalis-Bedfordia salicina-Pultenaea juniperina wet sclerophyll forest	PR
E. obliqua-Olearia lirata-P. juniperina wet sclerophyll forest	WR
Lowland eastern sedgey buttongrass moorland	WR
Stipa mollis-Danthonia tussock grassland	UR
Shrubby *E. amygdalina* forest	WR
Shrubby *E. ovata* woodland/forest	UR
Heathy *E. amygdalina* coastal forest	WR
Heathy *E.amygdalina* forest on sandstone	WR
Heathy *E. tenuiramis* forest	PR
Sedgey *E. amygdalina* woodland	WR
Shrubby *E. obliqua* forest	WR
Schoenus lepidosperma-Epacris lanuginosa-Empodisma minus heath	WR
Lepidosperma concavum-Cassytha glabella-Gonocarpus tetragynus heath	WR
Lepidosperma longitudinale aquatic sedgeland	WR
Stipa mollis-Danthonia setacea grassland	NS

* Largely derived from Kirkpatrick, J.B. *et al.* (1995).
† Note that 15% of the original area in secure reserves is used as the criterion for well reserved for mappable communities, whereas substantial areas in two or more viable, secure reserves are required for the well-reserved appellation for described plant communities.
‡ WR = well-reserved, PR = poorly-reserved, UR = unreserved, NS = no information available.

(3) *Eucalyptus amygdalina* heathy coastal forest/woodland
This is the most widespread vegetation type at Huntingfield. The mapping unit corresponds largely with floristic group 2. *E. amygdalina* dominates the tree stratum, which can be either of forest or woodland density. The eucalypts can be single-stemmed or multistemmed, depending on past disturbance. The ground stratum is a dense heath with a substantial admixture of bracken. Heathy *E. amygdalina* coastal forest (Duncan & Brown 1985) is the equivalent Statewide community.

(4) *Eucalyptus amygdalina* heathy forest on sandstone
This vegetation type is closely similar structurally and floristically to *E. amygdalina* heathy forest/woodland. However, rocks are generally frequent among the heath understorey, which tends to be sparser than that of community 3. *E. tenuiramis* and its hybrids with *E. amygdalina* occur as a subdominant in parts of this mapping unit. Heathy *E. amygdalina* forest on sandstone (Duncan & Brown 1985) is the equivalent Statewide community.

(5) Open heath
This relatively sparse heath vegetation corresponds largely with floristic community 1. *Acacia genistifolia* is the usual dominant and grasses and herbs are prominent beneath. This vegetation type occurs on the less sandy and better drained soils supporting heath. This vegetation type most closely resembles *Lepidosperma concavum-Cassytha glabella-Gonocarpus tetragynus* heath (Kirkpatrick 1977) among recognised Statewide communities.

(6) Closed heath
This dense heath vegetation is found in poorly drained situations on deep, leached sands. The most typical dominants are *Allocasuarina monilifera* and *Leptospermum scoparium.* Many of the quadrats in floristic group 3 fall within this vegetation type, which most closely corresponds to *Schoenus lepidosperma-Epacris lanuginosa-Empodisma minus* heath (Kirkpatrick 1977) among recognised Statewide communities.

(7) Sedgeland
This vegetation type largely corresponds with floristic group 4. Details of dominance and environment are given above. It most loosely fits lowland eastern sedgey buttongrass moorland (Jarman *et al.* 1988) among the recognised Statewide communities. Some of this mapping unit has a sufficient tree stratum to be classifiable as sedgey *Eucalyptus amygdalina* woodland (Duncan & Brown 1985).

(8) Grassland
Some small areas of vegetation dominated by *Stipa mollis* and *Danthonia setacea* occur within the open-heath vegetation type, with one area large enough to map. This may be a degradation stage rather than a stable community as it occurs along roadsides where clay is close to the surface. It falls within floristic group 1.

(9) Wetland
The one small, natural enclosed wetland in the estate is dominated by *Lepidosperma longitudinale. Restio complanatus* also occurs in this species poor vegetation type. The margin of the wetland is dominated by *Melaleuca squamea* and *M. squarrosa. L. longitudinale* aquatic sedgeland is the Statewide community best pertaining to this wetland. Artifical wetlands have been created by the damming of Coffee Creek. These are described by Duncan & Duncan (1995).

CONSERVATION STATUS OF PLANT COMMUNITIES AND SPECIES

Nine communities that are mappable on a statewide basis were located in the Huntingfield Estate (table 2). Of these communities only heath and buttongrass moorland were reserved at a level considered to be satisfactory (more than 15% of pre-European occurrence) in 1995 (Kirkpatrick *et al.* 1995). The remaining communities were poorly-reserved. Two of these, lowland tussock grassland and *Eucalyptus ovata* forest, have had most of their original area destroyed by land clearance and cultivation. These two communities occupy only a small proportion of the estate (fig. 2).

Of the described but non-mappable communities (those based on floristic combinations and combinations of understorey and overstorey dominance), fourteen were recognised from the estate (table 2). *Stipa mollis-Danthonia* tussock grassland (a previously undescribed community) and shrubby *Eucalyptus ovata* woodland/forest were not known from any secure reserve in the State in 1995. Heathy *E. tenuiramis* forest was poorly reserved, only being known from the Coal River Gorge Nature Reserve. *E. viminalis-Bedfordia salicina-Pultenaea juniperina* wet sclerophyll forest was also poorly reserved. The remaining communities were considered well reserved, in that they occur in viable areas in two or more secure reserves.

The recent land-use decisions made as a result of the Regional Forest Agreement Process, including the establishment of the Peter Murrell Nature Reserve within the study area, have resulted in a more secure conservation status for all the unreserved and poorly reserved communities indicated above. The Peter Murrell Nature Reserve contains areas of all these communities, and other secure reserves promised, or possible, under the agreement might further improve their reservation status.

Several species of conservation significance occur within the estate. *Prasophyllum concinnum* is an orchid which, at one time, was thought to be extinct, but was recently found within the estate (Ziegeler 1994). It has also recently been found in two secure reserves elsewhere in the State. Its status is now considered to be rare, rather than endangered. Other State-listed rare vascular plant species (*Threatened Species Act* 1997) found within the estate are *Caladenia alata*, which was also unreserved, *Juncus amabilis* and *Restio monocephalus.* The latter species is very common in the estate in heath and on the margins of buttongrass moorland.

A moss, *Archidium stellatum*, has been only recorded from the estate within Tasmania. However, this identification needs to be verified. Another moss found in the estate, *Breutelia affinis*, is poorly reserved within Tasmania (Moscal & Kirkpatrick 1997).

MANAGEMENT PROBLEMS

Small-scale open spaces are an important component of the local environment, especially in the vicinity of otherwise dense gound vegetation. The open spaces are important in maintaining the rich orchid flora of the estate. Consequently, some thought needs to be given to the processes which generate and maintain the multi-scale mosaic of these spaces.

In other parts of Tasmania, burrowing mammals, ant nests, fluctuating water tables, small-scale fires and local disease outbreaks variously contribute to this dynamic. In Huntingfield, periodically slashed fire breaks appear to have promoted the abundance of native orchids, including *Prasophyllum concinnum.*

Most of the 64 exotic plants found in the estate are confined to places that have been subject to nutrient addition and substantial ground disturbance or are naturally more fertile than the leached sands that cover most of the study area. The exotic species have the greatest cover in the Coffee Creek valley and where shellfish have been cleaned, leaving large European middens (fig. 3).

The exotic plant species that most threaten the integrity of the natural vegetation are a group of fire-adapted shrubs. These include two Australian native shrubs that do not occur naturally in southern Tasmania, *Acacia longifolia* and *A. retinodes.* Both produce hard-coated seeds in profusion. These seeds have their germination stimulated by fire. A group of introduced pea shrubs, *Chamaecytisus proliferus, Cytisus scoparius, Psoralea pinnata* and *Genista monspessulana,* are also adapted to store seeds in the soil and germinate prolifically after fire. Gorse (*Ulex europaeus*) not only does the same but also makes outstanding vegetative recovery. South African boneseed (*Chrysanthemoides monilifera*) is easily killed by fire but germinates profusely after it, and, unlike the previous species, is widely dispersed by birds who value the fleshy coating of its hard seed. Spanish heath (*Erica lusitanica*) while not having a wide dispersal range, spreads vegetatively, resprouts vigorously and germinates prolifically after fire. Pampas grass (*Cortaderia selloana*) resprouts after fire and has seed that is spread widely by wind. It is the most threatening of the herbaceous plants.

With the exception of Spanish heath and isolated individuals of pampas grass, the above species are confined to the open forest along Coffee Creek or to the disturbed areas behind houses on the eastern boundary. Spanish heath has established in relatively small numbers within the largest area of heath, where there are also small infestations of the bird-dispersed and fire-resistant blackberry (*Rubus fruticosus*).

Although most of the threatening exotic species are found in low numbers within the interior of the surviving bush, all, with the possible exception of blackberry, have the potential for exponential growth in numbers in the well drained part of the area. Pampas grass may be able to invade the poorly drained parts.

Many of these species, and some that are yet to invade the area, grow in the domestic gardens that partially abut the bush now and are likely to surround the bush in the future. It is important that invasive species are excluded from domestic horticulture within dispersal range, which is up to 400 m in the case of bird-dispersed species (Zacharek 1990).

Phytophthora cinnamomi, the cinnamon fungus, is a root-rotting exotic widespread in heaths and heathy woodland in lowland Tasmania (Podger *et al.* 1990). Localised dieback of the susceptible species, *Sprengelia incarnata,* and other epacrids, indicate its widespread presence in the area. It seems to be too late to take any action to prevent its spread.

Fire is a management problem in two ways. Firstly, the frequency of fire can be such that native species are threatened. This can happen with too frequent fire, when obligate seed regenerators, such as *Leptospermum glaucescens,* can be eliminated. Alternatively, too infrequent fire may

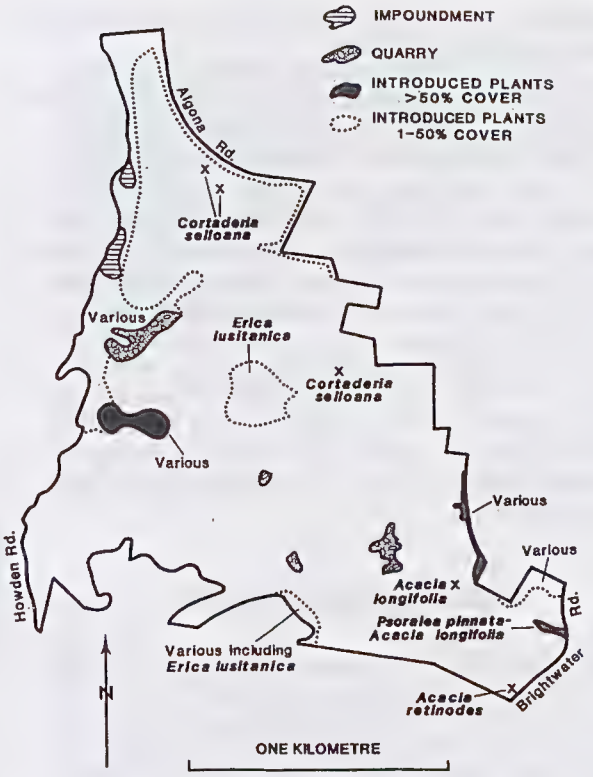


FIG. 3 — The distribution of environmental weed infestations in the Huntingfield Estate.

reduce or eliminate many of the smaller species, such as orchids, as the dominant shrubs form a closed canopy. Secondly, fire is a management problem, in that fires lit within bush on blowup days can threaten adjacent property. This creates a management imperative to minimise the chances of that spread. This means reducing fuel, at least on the boundaries, using fire or mechanical means.

While the ecological impacts of varying fire frequencies on heathy vegetation are not fully understood, recommended burning intervals tend to be between ten and 30 years. The rarity of *L. glaucescens* in Huntingfield tends to suggest that fires have been much more frequent than once every ten years over most of the estate.

It is considered to be important for biodiversity conservation in bush islands, the likely future of Huntingfield, that fires do not burn the whole area at once. This implies a patch burning strategy.

The fuel accumulation characteristics of heathy vegetation are such that fuel levels that could be dangerous to adjacent properties will accumulate if the ecologically acceptable frequencies are adopted. However, the major danger to property is high fuel levels close to houses. Thus, fuel reduction is largely a matter pertaining to the margins of the area.

Accessions of water and nutrients in heathy ecosystems have been shown to lead to deterioration in the native vegetation and invasion of exotic plants. Such accessions already occur where houses are in the upper parts of catchments, although their magnitude appears to be relatively small. Capture of drainage in sewerage systems or on domestic blocks will be necessary if there is not to be further down-catchment damage.

The dumping of rubbish is another major source of nutrients. The dumping of garden waste is particularly

dangerous as it combines nutrition with dispersal of potentially invasive species.

The area is used for the extraction of firewood, sand and native plants, all informally and illegally. The extraction of firewood is associated with the movement of vehicles off tracks, causing damage to soils and understorey vegetation.

As the only large area of accessible and effectively uncontrolled bush near the suburbs of Kingston and Blackmans Bay, Huntingfield is a playground for horse-riders, off-road vehicle enthusiasts, mountain bikers, dog walkers, walkers, runners and shooters. Juvenile trail-bikers are particularly numerous. The map of tracks in the area (fig. 4) may not include all of the large number of narrow bike trails that link the bulldozed lines, as these are not always perceptible on the aerial photographs. Mechanised recreationalists have caused a large amount of damage to the natural ecosystems of the area, particularly where they cross drainage lines.

GENERAL DISCUSSION

The Huntingfield area has a flora and vegetation with a high degree of similarity to other areas with infertile, sandy soils and similar rainfall elsewhere in the State, such as Lime Bay on the Tasman Peninsula (Kirkpatrick 1975) and the granitic country of the northeast of the State (Duncan & Brown 1995). However, its suburban situation presents a degree of difficulty in management well above that in similar areas, such as the Lime Bay Nature Reserve and the Mount William National Park. Nevertheless, this situation is an advantage in the process of educating the public on the values of the heathy ecosystems of Tasmania, as this is the closest area of such vegetation to a major population centre.

The native vegetation of the area should be able to persist in at least its present state of health in the long term, if substantial additions of nutrients to the soils can be avoided and control of potentially transforming weeds can be achieved. Neither of these requirements should be daunting tasks, especially if the present level of community involvement in management can be maintained.

ACKNOWLEDGEMENTS

Much of this work was done for the Huntingfield/Coffee Creek Landcare Group and was supported by a Save the Bush grant. The 1996 Vegetation Management class at the University of Tasmania helped collect much of the data. Andrew Zacharek and Mona Loofs also helped in the collection of the quadrat data. We are grateful to Hans Wapstra for information on orchid species distribution and Pieter van der Meer for access to his list of species of the Blackmans Bay area. Tony Moscal kindly collected and identified moss and liverwort species from the area. Guus van de Geer drew the figures.

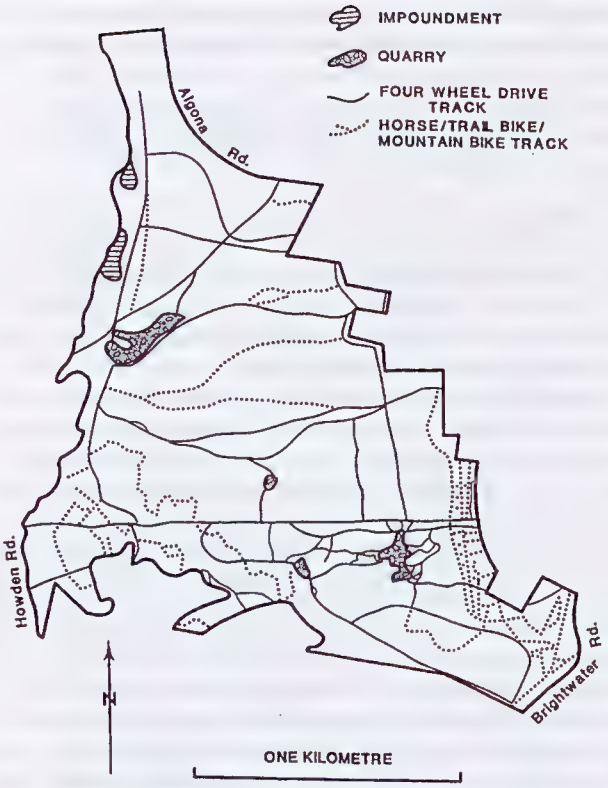


FIG. 4 — Tracks in Huntingfield.

REFERENCES

BUCHANAN, A.M., 1995: *A CENSUS OF THE VASCULAR PLANTS OF TASMANIA. Tasm. Herb. Occ. Publ.* 5. Tasmanian Herbarium, Hobart.

DUNCAN, F. & BROWN, M.J., 1985: *DRY SCLEROPHYLL VEGETATION IN TASMANIA. Wildl. Div. Tech. Rep.* 85/1. National Parks & Wildlife Service, Tasmania.

DUNCAN, F. & BROWN, M.J., 1995: Edaphics and fire — an interpretative ecology of lowland forest vegetation on granite in northeast Tasmania. *Proc. Linn. Soc. NSW* 115: 45–60.

DUNCAN, D. & DUNCAN, F., 1995: Vegetation resources and management in the Coffee Creek Reserve and the Huntingfield Estate. Report to the Huntingfield/Coffee Creek Landcare Group.

FLORA ADVISORY COUNCIL, 1994: *NATIVE HIGHER PLANT TAXA WHICH ARE RARE OR THREATENED IN TASMANIA.* Parks & Wildlife Service, Hobart.

HILL, M.O., 1979: *TWINSPAN: A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes.* Cornell University, New York.

JARMAN, S.J., KANTVILAS, G. & BROWN, M.J., 1988: *BUTTON-GRASS MOORLAND IN TASMANIA. Res. Rep.* 2. Tasmanian Forest Research Council Inc.

KIRKPATRICK, J.B., 1975: Phytosociological analysis of the vegetation of Lagoon Beach, Tasmania. *Pap. Proc. R. Soc. Tasm.* 109: 530–563.

KIRKPATRICK, J.B., 1977: *THE DISAPPEARING HEATH.* Tasmanian Conservation Trust, Hobart.

KIRKPATRICK, J.B. & BROWN, M.J., 1991: *RESERVATION ANALYSIS OF TASMANIAN FORESTS.* Resource Assessment Commission Forest and Timber Inquiry Consultancy Series FTC91/16: 131 pp.

KIRKPATRICK, J.B. & DICKINSON, K.J.M., 1984. *VEGETATION MAP OF TASMANIA, 1:500,000.* Forestry Commission, Tasmania.

KIRKPATRICK, J.B. & DICKINSON, K.J.M., 1986: Achievements, conflicts and concepts in Australian small-scale vegetation mapping. *Aust. Geogr. Stud.* 24: 224–234.

KIRKPATRICK, J.B., PEACOCK, R.J., CULLEN, P.J. & NEYLAND, M.G., 1988: *THE WET EUCALYPT FORESTS OF TASMANIA.* Tasmanian Conservation Trust, Hobart.

KIRKPATRICK, J.B., BARKER, P., BROWN, M.J., HARRIS, S. & MACKIE, R., 1995: *THE RESERVATION STATUS OF TASMANIAN VASCULAR PLANT COMMUNITIES. Wildl. Sci. Rep.* 95/4. Parks & Wildlife Service, Tasmania.

MOSCAL, A. & KIRKPATRICK, J.B., 1997: *ATLAS OF MOSSES AND LIVERWORTS IN TASMANIA.* A report to the Australian Heritage Commission from the Tasmanian Conservation Trust.

MUELLER-DOMBOIS, D. & ELLENBERG, H.,1974:. *AIMS AND METHODS OF VEGETATION ECOLOGY.* Wiley International, New York.

PODGER, F., PALZER, C. AND WARDLAW, T., 1990: A guide to the Tasmanian distribution of *Phytophthora cinnamomi* and its effects on native vegetation. *Tasforests* 2: 13–20.

PYRKE, A., 1990: Report on a botanical survey of the Coffee Creek area in the proposed Huntingfield development. Department of Geography and Environmental Studies, University of Tasmania.

ZACHAREK, A., 1990: Bush invasion by *Cotoneaster* spp. in Hobart. Unpubl. Grad.Dipl.Env.Stud. (Hons) thesis, Univ. Tasm.

ZIEGELER, D., 1994: PRASOPHYLLUM CONCINNUM *FLORA RECOVERY PLAN — MANAGEMENT PHASE. Wildl. Rep.* 94/11. Parks & Wildlife Service, Tasmania.

(accepted 5 July 1999)

APPENDIX 1

Species of vascular plant, mosses and liverworts observed in the Huntingfield Estate

(nomenclature after Buchanan 1995)

ANGIOSPERMAE

DICOTYLEDONAE

Apiaceae
- *Xanthosia dissecta*

Asteraceae
- **Arctotheca calendula*
- †*Bedfordia salicina*
- **Bellis perennis*
- †*Brachyscome spathulata* ssp. *glabra*
- *Cassinia aculeata*
- **Cirsium vulgare*
- **Chrysanthemoides monilifera*
- *Chrysocephalum apiculatum*
- *Cotula coronopifolia*
- *Gnaphalium collinum*
- *Helichrysum scorpioides*
- **Hypochoeris radicata*
- **Leontodon taraxacoides*
- *Leptinella reptans*
- *Leptorhynchos squamatus*
- *Olearia myrsinoides*
- *O. phlogopappa*
- *O. ramulosa*
- *Ozothamnus ferrugineus*
- **Picris echioides*
- *Senecio hispidulus*
- *S. linearifolius*
- *S. minimus*
- *S. quadridentatus*
- **S. vulgaris*
- **Sonchus asper*
- **S. oleraceus*
- **Taraxacum officinale*
- **Vellereophyton dealbatum*

Brassicaceae
- **Rorippa nasturtium-aquaticum*

Callitrichaceae
- **Callitriche stagnalis*

Campanulaceae
- *Lobelia gibbosa*
- *Wahlenbergia* sp.

Caryophyllaceae
- **Cerastium glomeratum*
- **Moenchia erecta*
- **Sagina procumbens*
- **Spergula arvensis*
- **Stellaria media*
- **S. pallida*

Casuarinaceae
- *Allocasuarina littoralis*
- *A. monilifera*

Clusiaceae
- *Hypericum gramineum*

Crassulaceae
- *Crassula sieberana*

Dilleniaceae
- *Hibbertia acicularis*
- *H. procumbens*
- *H. riparia*

Droseraceae
- *Drosera peltata* ssp. *auriculata*
- *D. peltata* ssp. *peltata*
- *D. pygmaea*

Epacridaceae
- *Astroloma humifusum*
- *Epacris impressa*
- *E. lanuginosa*
- *E. obtusifolia*
- *Leucopogon collinus*
- *L. ericoides*
- *L. virgatus*
- *Sprengelia incarnata*
- *Styphelia adscendens*

Ericaceae
- **Erica lusitanica*

Euphorbiaceae
- *Amperea xiphoclada*

Fabaceae
- *Aotus ericoides*
- *Bossiaea cinerea*
- *B. prostrata*
- **Chamaecytisus proliferus*
- **Cytisus scoparius*
- *Daviesia ulicifolia*
- *Dillwynia glaberrima*
- **Genista monspessulana*
- *Gompholobium huegelii*
- **Lotus pedunculatus*
- *Oxylobium ellipticum*
- **Psoralea pinnata*
- *Pultenaea dentata*
- *P. juniperina*
- *Sphaerolobium minus*
- **Trifolium dubium*
- **T. repens*
- **Ulex europaeus*
- **Vicia sativa*

Fumariaceae
- **Fumaria muralis*

Gentianaceae
- **Centaurium erythraea*

Geraniaceae
- *Geranium potentilloides*

Goodeniaceae
- *Goodenia lanata*

Haloragaceae
- *Gonocarpus micranthus*
- *G. tetragynus*
- *G. teucrioides*

Lamiaceae
- **Prunella vulgaris*

Lauraceae
- *Cassytha glabella*
- *C. pubescens*

Lentibulariaceae
- *Utricularia dichotoma*
- *U. lateriflora*

Loganiaceae
- *Mitrasacme pilosa*

Mimosaceae
- *Acacia dealbata*
- *A. genistifolia*
- **A. longifolia*

APPENDIX 1 cont.

Mimosaceae (cont.)
A. melanoxylon
A. myrtifolia
**Acacia retinodes*
A. stricta
A. suaveolens
A. verticillata
Myrtaceae
Baeckea ramosissima
Callistemon pallidus
†*Eucalyptus amygdalina*
E. obliqua
E. ovata
†*E. tenuiramis*
E. viminalis
†*Leptospermum glaucescens*
L. scoparium
Melaleuca squamea
M. squarrosa
Onagraceae
Epilobium hirtigerum
Oxalidaceae
Oxalis perennans
Pittosporaceae
Bursaria spinosa
Plantaginaceae
**Plantago coronopus*
**P. lanceolata*
Polygonaceae
**Acetosella vulgaris*
**Rumex crispus*
Polygalaceae
Comesperma volubile
Portulacaceae
**Calandrinia caulescens*
Primulaceae
**Anagallis arvensis*
Proteaceae
Banksia marginata
†*Lomatia tinctoria*
Persoonia juniperina
Ranunculaceae
Clematis aristata
**Ranunculus muricatus*
Rosaceae
Acaena novae-zelandiae
**Crataegus monogyna*
**Rosa rubiginosa*
**Rubus fruticosus*
Rubiaceae
**Galium aparine*
Opercularia varia
**Sherardia arvensis*
Rutaceae
Boronia parviflora
Zieria arborescens
Salicaceae
**Salix babylonica*
Santalaceae
Exocarpos cupressiformis
Leptomeria drupacea
Stackhousiaceae
Stackhousia monogyna
Stylidiaceae
Stylidium graminifolium
Thymeleaceae
Pimelea humilis
P. linifolia
Tremandraceae
Tetratheca labillardierei
T. pilosa
Violaceae
Viola cleistogamoides

MONOCOTYLEDONAE
Centrolepidaceae
Centrolepis sp.
Cyperaceae
Baumea acuta
B. tetragona
Carex appressa
Gahnia grandis
G. radula
Gymnoschoenus sphaerocephalus
Isolepis cernua
I. inundata
I. nodosa
Lepidosperma concavum
L. elatius
L. filiforme
L. gunnii
L. laterale
L. longitudinale
Schoenus apogon
S. lepidosperma
Tetraria capillaris
Iridaceae
Diplarrena moraea
Patersonia fragilis
Juncaceae
‡*Juncus amabilis* R2 UR
**J. articulatus*
**J. effusus*
J. gregiflorus
J. pallidus
J. procerus
J. sarophorus
Luzula flaccida
Liliaceae
Dianella revoluta
D. tasmanica
Drymophila cyanocarpa
Thelionema caespitosum
Orchidaceae
‡*Caladenia alata* R2 UR
†*C. atrata*
C. carnea aff. *fuscata*
C. clavigera
C. dilatata
C. gracilis
C. patersonii
Caleana major
Calochilus herbaceus
C. paludosus
C. robertsonii
Chiloglottis gunnii
C. reflexa
Diuris pardina
D. sulphurea
Eriochilus cucullatus
Genoplesium archeri
Glossodia major
Microtis arenaria
M. unifolia
Paracaleana minor
†*Prasophyllum concinnum* R2
Pterostylis aphylla
P. nana
P. nutans
P. parviflora
P. plumosa
Thelymitra arenaria
T. aristata
T. cyanea
T. ixioides
T. nuda
T. pauciflora
T. rubra
T. venosa
Poaceae
**Agrostis capillaris*
A. sp.
**Aira caryophyllea*
**Alopecurus geniculatus*
**Anthoxanthum odoratum*
**Bromus diandrus*
**B. sterilis*
**Cortaderia selloana*
**Dactylis glomerata*
Danthonia pilosa
D. setacea
Deyeuxia quadriseta
Dichelachne crinita
D. sp.
Ehrharta acuminata
E. distichophylla
E. stipoides
Elymus scaber
**Glyceria declinata*
**Holcus lanatus*
**Poa annua*
P. labillardierei
P. sieberiana
Stipa flavescens
S. mollis
**Vulpia bromoides*
**V. megalura*
Restionaceae
Empodisma minus
Hypolaena fastigiata
Leptocarpus tenax
Lepyrodia muelleri
L. tasmanica
Restio complanatus
‡*R. monocephalus* R2
Typhaceae
**Typha orientalis*
Xanthorrhoeaceae
Lomandra longifolia

APPENDIX 1 cont.

Xyridacaee
†*Xyris gracilis* ssp. *tasmanica*
†*X. marginata*
X. operculata

PTERIDOPHYTA
Aspidaceae
Polystichum proliferum
Aspleniaceae
Asplenium flabellifolium
Blechnaceae
Blechnum minus
B. nudum
B. wattsii
Dennstaedtiaceae
Pteridium esculentum
Dicksoniaceae
Dicksonia antarctica
Gleicheniaceae
Gleichenia dicarpa
Lindsaeaceae
Lindsaya linearis
Schizeaceae
Schizaea sp.
Selaginellaceae
Selaginella uliginosa

BRYOPHYTA
Archidiaceae
‡*Archidium stellatum* UR
Aulicomniaceae
Leptotheca gaudichaudii var. *gaudichaudii*
Bartramiaceae
‡*Breutelia affinis* PR
Bryaceae
Bryum argenteum
B. caespiticium
B. dichotomum
B. pachytheca
Dicranaceae
Campylopus clavatus
C. introflexus ssp. *pudicus*
Ditrichaceae
Ceratodon purpureus
Ditrichum cylindricarpum
D. difficile
Fissidentaceae
Fissidens leptocladus
Funariaceae
Funaria hygrometrica
Grimmiaceae
Grimmia pulvinata
Hookeriaceae
Calyptrochaeta apiculata
Orthotrichaceae
Zygodon menziesii
Polytrichaceae
Polytrichum juniperinum var. *australe*
Pottiaceae
Barbula calycina
B. crinita
Didymodon australasiae
Gymnostomum calcareum
Tortula muralis
Triquetrella papillata
Sphagnaceae
Sphagnum australe
S. cristatum

HEPATICA
Acrobolbaceae
Goebelobryum unguiculatum
Lethocolea squamata
Cephaloziellaceae
Cephaloziella exiliflora
Geocalycaceae
Chiloscyphus semiteres var. *semiteres*
Heteroscyphus coalitus
H. varians
Lepidozoaceae
Hyalolepidozia longiscypha
Kurzia compacta
Lepidozia laevifolia
Marchantiaceae
Lunularia cruciata

* Introduced species.
† Tasmanian endemic species.
‡ R2 = rare in Tasmania (Flora Advisory Committee 1994). UR = not known to occur in any other secure reserve. PR = poorly-reserved (only known to occur in one population in one other secure reserve).

A NEW SPECIES OF *EUCHITON* (GNAPHALIEAE: ASTERACEAE) FROM SOUTHERN TASMANIA, AUSTRALIA

by Alex M. Buchanan

(with one text-figure and one plate)

BUCHANAN, A.M., 1999 (31:x): A New Species of *Euchiton* (Gnaphalieae: Asteraceae) from Southern Tasmania, Australia. *Pap. Proc. R. Soc. Tasm.* 133(1): 115–116. ISSN 0080–4703. Tasmanian Herbarium, GPO Box 252-04, Hobart, Tasmania, Australia 7001.

Euchiton litticola (Asteraceae) from western and southern Tasmanian coasts is described as new. Ecological notes and a distribution map are provided.

Key Words: *Euchiton*, coastal zone, angiosperm, Tasmania.

INTRODUCTION

Fieldwork on the southwestern coast of Tasmania has focussed attention on a previously overlooked, diminutive member of the genus *Euchiton*. Formerly this species would have been included in *Gnaphalium* sens. lat., but most Australian taxa are now placed in *Euchiton*, which is distinguished by the two papillae on each epidermal cell of the achenes and, usually, its stoloniferous habit (Drury 1972, Holub 1974, Anderberg 1991). This small plant inhabits the salt-spray zone and extends out onto the slopes of headlands above the surf.

TAXONOMY

Euchiton litticola A.M. Buchanan sp. nov.

Euchiton collino Cass. affinis sed habitu minore rosulatoque, scapo brevi, modo ad 60 mm longo, capitulo plerumque solitano, folus linearibus, 10–30 mm longis et 2–3 mm latis.

Type: Tasmania, southwest region, mouth of Oxley Creek, Spero Bay, 42°37'S, 145°19'E, *A.M. Buchanan 2581*, 16.i.1984.
Holotype: HO 98736 !
Isotypes: MEL, NSW, PERTH.

Stoloniferous perennial, forming leafy rosettes to 50 mm wide (pl. 1); leaves narrow-linear (10–30 mm x 2–3 mm), grey-green and glabrous above, white-tomentose below except on the midvein; scape short, especially when flowering, but elongating in fruit to 10–20 mm, occasionally to 60 mm, tomentose, with 3–4 linear bracts 5–8 mm long; capitula solitary (occasionally several together), 6–9 mm in diameter; involucral bracts 15–20, linear-oblong, to 5 mm long, outer ones wider and tomentose on abaxial face; disk glabrous, pitted; bisexual florets 5–8, narrowly cylindrical; female florets c.40, filiform; corollas purple tinted, 3–4 mm long, almost equalling the pappus; achenes fusiform, flattened, with scattered clavate hairs, 1 mm long.

PLATE 1
Habit. Four short, flowering scapes are visible among the leaves. The one long, fruiting scape has already shed its achenes.

FIG. 1 — Geographical distribution. Each dot represents a herbarium specimen held at HO.

ETYMOLOGY

The epithet *litticola* is from the Latin: *littus,* the sea shore and *cola,* dweller.

DISTRIBUTION AND ECOLOGY

Euchiton litticola is endemic to western and southern Tasmania where it occurs along the coast between Rupert Point in the west and Dolomieu Point in the east (fig. 1). It is confined to the narrow littoral zone, to the seaward of the usually windswept coastal shrubbery, extending out onto rocks that are drenched with salt spray during storms. It is among the few angiosperms, e.g. *Plantago triantha,* that reach such limits. On cliffs it forms dense, mat-like colonies within rock crevices.

NOTES

Euchiton litticola is unlike any other species of *Euchiton* in Tasmania in having narrow-linear leaves. It has, however, been mistaken for *Helichrysum pumilum* var. *pumilum* which is common in sedgeland communities adjacent to the coast in southwestern Tasmania. In the field, it can be distinguished from the latter by its narrower, soft, curved leaves and its narrow, pale-brown, gnaphalioid involucral bracts; in contrast, the leaves of *Helichrysum pumilum* var. *pumilum* are rigid and mostly straight, and the involucral bracts are elliptical and conspicuously white or pink in colour. Two similar species of *Euchiton* with solitary heads and narrow leaves are *E. traversii* of southeastern Australia, Tasmania and New Zealand, and *E. ensifer* of New Zealand, but in neither do the leaves attain the long, narrow- linear shape as in *E. litticola.* Furthermore, these are plants of montane and subalpine habitats.

CONSERVATION STATUS

Euchiton litticola is common on coastal rocks in the South West National Park and does not fulfil the criteria for listing in the schedules of the *Threatened Species Protection Act,* 1995.

REPRESENTATIVE SPECIMENS EXAMINED (ALL AT HO)

Listed in sequence from west to east: Rupert Point, *W.D. Jackson 51,* Jan 1954; Remine, *L. Rodway s.n.,* Oct 1893; 1.5 km north of Gorge Point, *A. Moscal 16872,* 8 Jan 1989; Pennerowne Point, *A.M. Buchanan 2809,* 26 Jan 1984; Niblin Point, *A.M. Buchanan 2481,* 13 Jan 1984; Pegg Creek, Hartwell Cove, *A. Moscal 10039,* 17 Mar 1985; near mouth of Flat Creek, *A.M. Buchanan 5778,* 22 Feb 1985; Mainwaring Inlet, 1 km from mouth, *A. Moscal 9755,* 23 Feb 1985; Mulcahy Bay, *A.M. Buchanan 8015,* 19 Jan 1986; SE shores of Bathurst Harbour, *J.B.Kirkpatrick s.n.,* 12 Apr 1978; Wilson Bight, *A.Moscal 13984,* 14 Jan 1987; Hidden Bay, *A.M.Buchanan 522,* 26 Feb 1981, duplicate at CHR; Cox Bight, *A.M. Buchanan 3388,* 22 Apr 1984; Louisa Bay, *A. Moscal 9641,* 18 Feb 1985; Shoemaker Bay, *A.M. Buchanan 3518,* 27 Apr 1984; South Cape Bay, *J.B. Kirkpatrick s.n.,* Jan 1982; between Bivouac Bay and Dolomieu Point, *A.M. Buchanan 11890,* 30 Jan 1991.

ACKNOWLEDGEMENTS

I am particularly grateful to Paul Wilson for assistance in interpreting the achenial hairs and to Neville Walsh for his helpful comments on the manuscript. Gintaras Kantvilas corrected my attempts at Latin.

REFERENCES

ANDERBERG, A., 1991: Taxonomy and phylogeny of the tribe Gnaphalieae (Asteraceae). *Oper. Bot.* 104: 1–195.

DRURY, D.G., 1972: The cluster and solitary-headed cudweeds native to New Zealand: (*Gnaphalium* Section *Euchiton* - Compositae). *N.Z. J. Bot.* 10(1): 112-179.

HOLUB, J., 1974: New names in phanerogamae 3. *Folia Geobot. Phytotaxon.* 9: 261–275.

(accepted 5 July 1999)

ROYAL SOCIETY OF TASMANIA
Papers and Proceedings
Guide for Authors

SCOPE AND AUTHORSHIP

Papers published by the Royal Society of Tasmania in its annual volume of *Papers and Proceedings* commonly deal with Tasmanian topics or those relevant to Tasmania. Most authors are Tasmanian residents or those with a connection with Tasmania. The subject matter is usually within the natural sciences or history, but papers in other areas may be published. They should embody the results of a significant piece of original work or an original synthesis or review.

PAPERS

Papers may be submitted by members of the Society or by non-members. They should be presented, with any relevant figures or plates, in such a form that revising and editing can be readily carried out and the evidence offered can be checked, if original, or easily traced, if quoted. Submission implies that the contents are original and have not been published previously in any form, and that no similar manuscript will be submitted elsewhere. The manuscripts should be forwarded to the Honorary Editor, The Royal Society of Tasmania, GPO Box 1166M, Hobart, Tasmania, Australia 7001. Please indicate the person to whom editorial queries, proofs etc. should be addressed.

The Council of the Society will take into consideration the advice of at least two reviewers before making a decision for or against acceptance of the paper for publication. That decision will be final. Once accepted, papers and their copyright belong to the Society. However, an author may copy his or her paper for distribution as a reprint and reproduction of synopses in abstracting journals is authorised.

Permission to use material printed by the Society in later publications — books, reviews, text-books etc — can be obtained upon application to the Council of the Society.

STYLE

The Editor reserves the right to adjust the text for conformity of style and publication standards.

Text

The text should be typed, double-spaced, on one side of A4 paper. The pages, including references, figure explanations and appendices should be serially numbered. Three copies of the paper (including good copies of the illustrations) should be sent initially, the author retaining a fourth copy. Upon acceptance of a paper, authors are asked to submit a final version as two hard copies or, preferably, as a hard copy and a disk or other electronic form; for compatibility please consult the Honorary Editor. If the paper is not accepted, one copy will be retained by the Society, the others returned to the author.

The manuscript should open with a title, which should be concise but informative, the name(s) of the author(s), the number of tables, text-figures and plates, and the institutional affinity and contact address of each author. An abstract should follow (not more than about 200 words in length) and a list of key words (2–10) to represent the subject matter in abstracting journals should be supplied.

The title, if short (not more than 44 letters long), will be used as a running head on right-hand pages in the printed paper; if the title is longer, a suitable running head may be supplied by the authors or, if not, will be provided by the Editor. Acknowledgement of support, help received etc. should be included at the end of the text.

For ease in comprehension, the text may be arranged under appropriate headings e.g. Introduction, Methods and Results, Discussion, Conclusions, Acknowledgements etc. with subheadings where applicable. Footnotes are not used in the text, but end-notes may be used.

Citations in the text of published written material should take a form according to the context e.g. Brown (1983), Brown & Green (1985), Brown *et al.* (1987), Brown *et al.* (in press), (Brown 1983). Information based on work by one of the authors of a multi-authored paper may be cited, if necessary, in the form "Green (pers. obs)". Reference to information supplied personally to the author(s) is noted in the text as "T.O. White (pers. comm.)" but not included in the list of references. Such information should be used only with the express (and preferably written) permission of the informant. It is helpful to the reader if the relevant page number within a lengthy cited work is also included e.g. (1983: 110). A list containing details of all references cited in the paper, but none not so cited, must be included. Authors should ensure consistency of spellings of names and of dates between the text citations and the reference list. Citation of publications "in press" may be accepted but "in preparation" should be avoided. The format of references in the reference list should conform to that used in recent volumes of the journal (the Editor can supply a copy of such a list upon request).

Tables and Illustrations

These should be numbered consecutively (table 1, table 2 etc.) in the order of first reference to them in the text. Capital letters, roman numerals and lower-case letters can be used in that order if needed, e.g. figure 1A, plate 2B(i); tables and illustrations should be referred to in the text specifically by their number. The author's name and the figure or plate number should be shown in soft pencil on the back of each illustration. Tables and illustrations should be designed so that the top is at the head or at the left-hand side of the page with printing oriented appropriately.

Tables

Titles should be brief, additional information being conveyed in a note, preferably below the table or incorporated in it.

Tables should be either (a) 65 lines or less in depth, each line of no more than 130 characters and spaces in length, or (b) 42 lines or less in depth, each line of no more than 190 characters and spaces. These dimensions include the title, explanatory material and column headings.

Illustrations

Illustrations will normally be reproduced in black and white. Colour illustrations may be used but authors will be expected to bear the extra cost of printing in colour. Captions must be supplied for all illustrations. Symbols used in the illustrations to convey information should be explained in a key within the artwork, rather than in the caption. Bar scales or objects of known or stated dimensions should be used to show the scale of illustrations wherever possible, as these retain their relative size upon reduction.

The maximum dimensions for illustrations, when printed, are 250 by 167 mm, including captions. Wherever possible, illustrations will be fitted into a single column (width 80 mm). Care should be taken to ensure that lines, letters and symbols used in illustrations are of a size and weight to stand the likely reduction to the printed size without breaking up, becoming too faint, filling in or becoming too small for ready legibility. The smallest letter or number, after reduction, should be not less than 2 mm high and, on the axes of graphs, 2.5 or 3 mm high. Computer drafted figures are acceptable, subject to clarity and legibility after reduction. PICT,TIFF, JPG, EPS formats are preferred.

Appendices

Material presented as Appendices may be accepted at the Editor's discretion but may be printed in a smaller type than the body of the paper.

CONVENTIONS

Abbreviations of words and of titles of periodicals in the list of references should be as recommended in the most recent edition of the *Style Manual for Authors, Editors and Printers* published by the Australian Government Publishing Service. The treatment recommended in that manual with respect to biological names should be followed.

The Botanical, Zoological and Stratigraphic Codes of Nomenclature should be fully observed.

Use of SI units of measurement is strongly preferred where consistent with the means of measurement.

In general the editorial panel follows the current edition of the *Style Manual.*

COSTS

Due to publication costs, texts should be made concise (but avoiding ambiguity) and tables and illustration should be used sparingly, both for economy and for maximum effect in the published form. Grants from author's institutions or elsewhere to support publication should be secured if possible. Authors are responsible for costs of alterations, other than minor corrections, to proofs. Page charges will normally be levied on the eleventh and each subsequent page of a paper as printed. Enquiries as to this charge should be directed to the Hon. Editor. As noted above, a charge to cover the extra cost of printing colour illustrations, will normally be made.

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 133(1)

Contents

page

Annual report iii

Refereed papers:

JACKSON, W.D. — The Tasmanian legacy of man and fire 1

BROTHERS, N. & HARRIS, S. — The effects of fire on burrow-nesting seabirds particularly short-tailed shearwaters *(Puffinus tenuirostris)* and their habitat in Tasmania 15

MEGGS, J.M. & TAYLOR, R.J. — Distribution and conservation status of the Mt Mangana stag beetle, *Lissotes menalcas* (Coleoptera: Lucanidae) 23

BANKS, M.R., & LEAMAN, D.E. — Charles Darwin's field notes on the geology of Hobart Town — a modern appraisal 29

LING, J.K. — Elephant seal oil cargoes from King Island, Bass Strait, 1802–1819: with estimates of numbers killed and size of the original population 51

MELVILLE, J. & SWAIN, R. — Habitat associations and natural history of the Tasmanian "snow skinks" (*Niveoscincus* spp.) 57

LEAMAN, D.E. — The nature of jointing, Tasman Peninsula, southern Tasmania 65

SMART, D., RUBIDGE, S., MCCARTNEY, P. & VAN DEN BROEK, C. — Tasmania's aquaculture industry: a ten-year review of improved diving safety 77

HARRIS, S. & MCKENNY, H. — Preservation Island, Furneaux Group: Two hundred years of vegetation change 85

KIRKPATRICK, J.B. — The characteristics and management problems of the vegetation and flora of the Huntingfield Area, southern Tasmania 103

BUCHANAN, A.M. — A New Species of *Euchiton* (Gnaphalieae: Asteraceae) from Southern Tasmania, Australia 115

Guide to authors 117

Publication of this volume was generously supported by the Government of Tasmania and the University of Tasmania.

512